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National Transportation Safety Board Special Investigation Report
Inspection and Testing of Railroad Tank Cars

(U.S.) National Transportation Safety Board, Washington, DC

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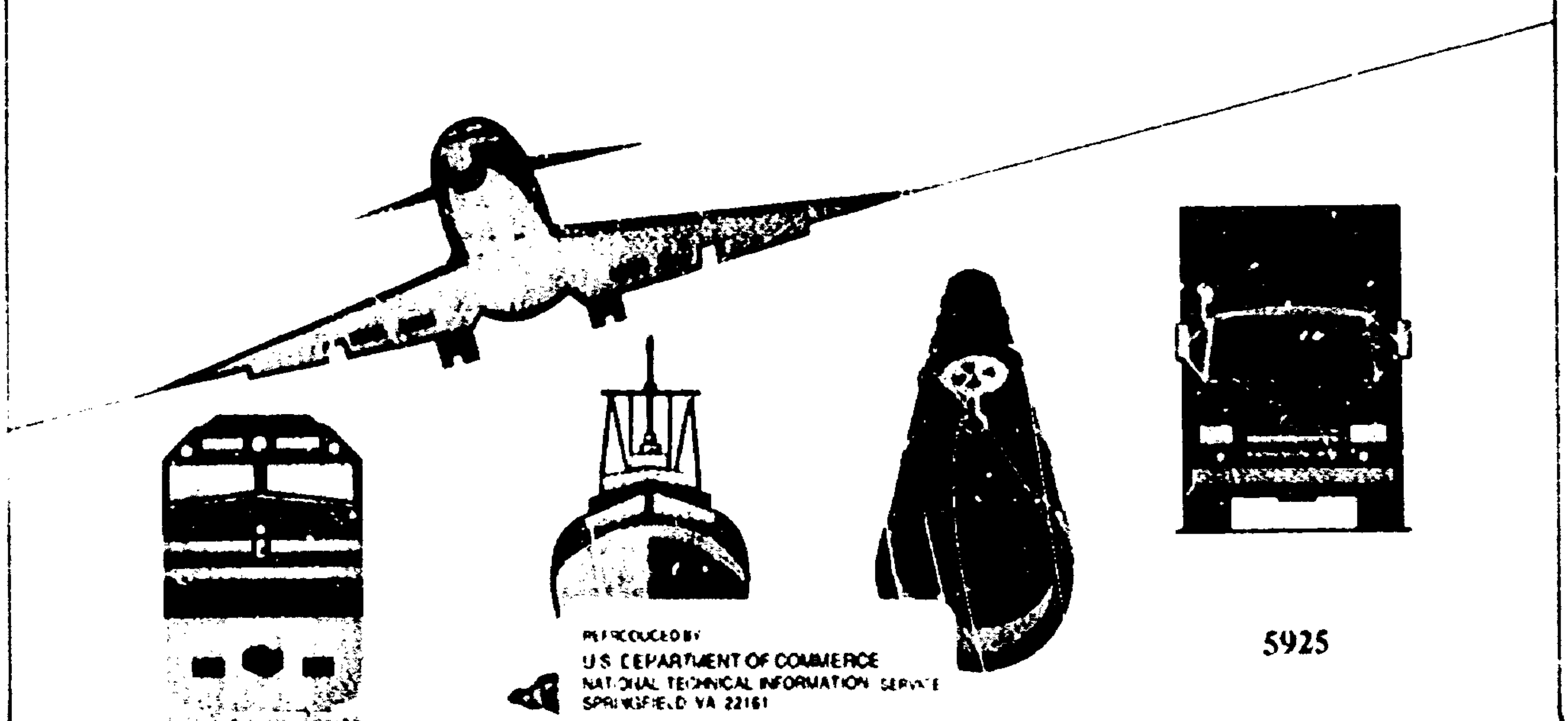
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

INSPECTION AND TESTING OF RAILROAD TANK CARS



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National Transportation Safety Board. 1992. Inspection and testing of railroad tank cars. Special Investigation Report NTSB/SIR-92/05. Washington, DC.

This special investigation was prompted by two 1992 railroad accidents involving the structural failures of a dual diameter tank car and a nonpressure tank car transporting hazardous materials. The failures resulted from preexisting cracks that had gone undetected. The special investigation also addresses failures of stub sills on various types of tank cars that resulted from undetected cracks in welds. The report discusses: (1) the current Department of Transportation (DOT) requirements for the periodic inspection and testing of DOT specification tank cars that transport hazardous materials; (2) the effectiveness of the current DOT requirements for the detection of cracks and other structural defects; and (3) the effectiveness of hydrostatic tests and other nondestructive testing methods for the detection of cracks and other structural defects. Recommendations addressing these concerns were made to the Federal Railroad Administration, the Research and Special Programs Administration, the Association of American Railroads, the Railway Progress Institute, and the Chlorine Institute.

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

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INSPECTION AND TESTING OF RAILROAD TANK CARS

Special Investigation Report

Special Investigation Report NTSB/SIR-92/05
Notation 5925

National Transportation
Safety Board

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December 1992

Contents

Executive Summary

On January 18, 1992, a U.S. Department of Transportation (DOT) specification tank car containing 30,700 gallons of propane, a flammable gas, fractured and separated along a circumferential weld when the train it was in began to move at Dragon, Mississippi. The separation resulted in the sudden and complete release of the entire load of propane from the dual diameter tank car. There was metallurgical evidence of a preexisting crack at the origin of the fracture. Postaccident testing and inspection of 108 other dual diameter tank cars of the same design revealed that 40 tank cars had cracks in the same location; 25 of the 40 with cracks had been tested and inspected, since 1988, under DOT periodic testing and inspection regulations, including 13 that were retested and reinspected in 1991 and 1992.

On March 25, 1992, a DOT specification tank car containing about 13,000 gallons of sulfuric acid cracked circumferentially when the train it was in began to move. This crack resulted in the release of the entire cargo. There was also metallurgical evidence of a preexisting crack in the area of the failure. At the time of the accident, the tank car was transporting its first cargo since it had been retested and reinspected in February 1992.

In addition to these accidents, cracking and structural failure at stub sill-to-tank car attachments on various classes of DOT specification tank cars have been noted since the mid-1980s.

Because of the nature of these structural failures, the National Transportation Safety Board conducted a special investigation into the adequacy of the DOT regulations pertaining to the periodic testing and inspection of DOT specification tank cars. As a part of its special investigation, the Safety Board also examined current industry practices and standards for testing and inspecting tank cars and the application of various methods of nondestructive testing for DOT specification tank cars.

The safety issue discussed in this report is:

- The adequacy of U.S. Department of Transportation regulations for the inspection and testing of DOT specification tank cars.

Safety recommendations addressing this issue were made to the Federal Railroad Administration and the Research and Special Programs Administration of the U.S. Department of Transportation, the Association of American Railroads, the Railway Progress Institute, and the Chlorine Institute.

Introduction

The National Transportation Safety Board conducted a special investigation on the inspection and testing of railroad tank cars in response to two accidents in which hazardous materials were released because of a structural failure of the tank car. The first accident occurred on January 18, 1992, in Dragon, Mississippi, and involved a U.S. Department of Transportation (DOT) specification 112J340W[1] dual diameter tank car that was operated by Conoco, Inc. (Conoco), and contained about 30,700 gallons of liquefied propane. The tank car, which was designed and built by General American Transportation Corporation (GATC) and had a load bearing capacity of 125 tons, fractured and separated along a circumferential weld where the transition section is joined to the large diameter cylinder of the tank. The separation resulted in the release and ignition of the entire cargo of propane. There was metallurgical evidence of a preexisting crack at the origin of the fracture. Postaccident testing and inspection of 108 other DOT class 112 dual diameter tank cars of the same GATC design found that 40 tank cars had cracks in the same location as that on the tank car that separated in Dragon, Mississippi.

A second accident occurred on March 25, 1992, in Kettle Falls, Washington, and involved a DOT specification 111A100W2 tank car that contained about 13,000 gallons of sulfuric acid. This tank car was built and operated by the Union Tank Car Company (Union). The tank car cracked at the bottom center of the tank along a circumferential weld, resulting in the release of all of the sulfuric acid.

Further, the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA) have been investigating cracking in welds at stub sill-to-tank car attachments on all types of DOT specification tank cars. Cracking at the stub sill-to-tank car connection has resulted in the propagation of the crack into the stub sill and separation of the sill from the tank.

According to the Research and Special Programs Administration's (RSPA) Hazardous Materials Information System (HMIS), there were 91 reported incidents for the 5-year period from 1987 through 1991 in which hazardous materials were released from DOT specification tank cars and attributed to cracks, fatigue, or failures of weld seams of the tank car. Review of the 91 individual incident reports indicated that about 41 of the incidents were reportedly caused by structural failures in the tank shell. These incidents typically involved small releases.

The Railway Progress Institute (RPI)[2] estimates that there are nearly 104,000 DOT specification tank cars, comprising about 55 percent of the tank car fleet currently in service and that can be used for the transportation of hazardous materials. The non-DOT specification tank cars that comprise the remainder of the tank car fleet are used to transport nonhazardous materials.

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[1] The alpha-numeric specification designates the DOT class of tank car and design specifications such as materials of construction, tank pressure, head shields, thermal protection, and jackets.

[2] The Railway Progress Institute is an association whose members own, manage, or lease nearly 121,000 tank cars, which is about 64 percent of the Nation's tank car fleet.

Because of the structural problems noted and the large number of DOT specification tank cars in service, the Safety Board's special investigation addressed (1) the current DOT requirements for the periodic inspection and testing of DOT specification tank cars that transport hazardous materials; (2) the effectiveness of the current DOT requirements for the detection of cracks and other structural defects; and (3) the effectiveness of hydrostatic tests and other nondestructive testing methods for the detection of cracks and other structural defects.

Structural Problems Noted

Dual Diameter Pressure Tank Cars

Accident at Dragon, Mississippi.—About 12:40 p.m. local time on January 18, 1992, three tank cars in Norfolk Southern Corporation freight train 326A8 derailed between mileposts 80 and 81 at Dragon, Mississippi. The derailed tank cars (UTLX 89170, CONX 9101, and CHVX 180130) each contained more than 30,000 gallons of liquefied propane and were the 71st, 72nd, and 73rd cars, respectively, behind 4 locomotives. The train contained 84 cars, was 5,525 feet long, and weighed 7,045 tons.

Train 326A8 was assembled on the morning of January 18 at Dragon. About 35 tank cars, including the 3 tank cars involved in the accident, were added to the train when it was assembled. About 30 minutes before the accident, the crew of northbound train 326A8 was instructed to hold on a side track until a southbound train passed on the main track. Because the traincrew had been advised that their train might be holding for a while, they decided to uncouple the train at the Enterprise crossing (the site of the derailment) so that the crossing would not be blocked to road traffic. The traincrew recoupled the train about 20 minutes later, and moved the train forward about 25 car lengths on the side track. Train 326A8 then stopped and continued to hold on the side track for another 5 to 10 minutes. When the main track was clear, the northbound train began to move from the side track onto the main track. The train moved about two engine lengths when it had an uncommanded emergency brake application. Readouts from the event recorders on the locomotives indicated that the train was traveling about 2 to 5 mph when the emergency brake application occurred.

A Norfolk Southern employee, who had been assisting the traincrew and was standing next to the locomotives as the train began to move, saw a white vapor cloud from the south end of the train. He stated to Safety Board investigators that several seconds, but not more than a minute, after seeing the vapor cloud, it ignited into a fireball. Other witnesses reported hearing a loud noise and seeing a large white cloud about 5 seconds later. Some witnesses stated that the vapor cloud extended from the ground to above trees that were estimated to be 100 feet in height. These witnesses also stated that several seconds passed before the cloud ignited into a fireball.

The A-end of CONX 9101, which was the trailing end, had separated circumferentially, resulting in the derailment of CONX 9101 and the tank cars coupled to each end of CONX 9101 (fig. 1). All of the cargo from CONX 9101, 30,700 gallons of propane, which is regulated as a flammable gas by the DOT, was released; no cargo was released from either of the adjacent cars, UTLX 89170 or CHVX 180130.

There were no injuries or evacuations. There was fire and heat damage to a vacant home and to the facilities of two liquefied petroleum gas terminals adjacent to the tracks. There was negligible environmental damage. Total property damage was estimated to be about $400,000.

Tank Car Information.—CONX 9101 was a DOT specification 112J340W dual diameter tank car. The tank had a larger diameter at its midsection than at its end sections, which were located over the running gear. An angled transition section joined the large and small diameter sections (fig. 2). The tank car was under a long-term lease to Conoco; however, at the time of the accident, Conoco had subleased the tank car to Ferrellgas. Conoco was

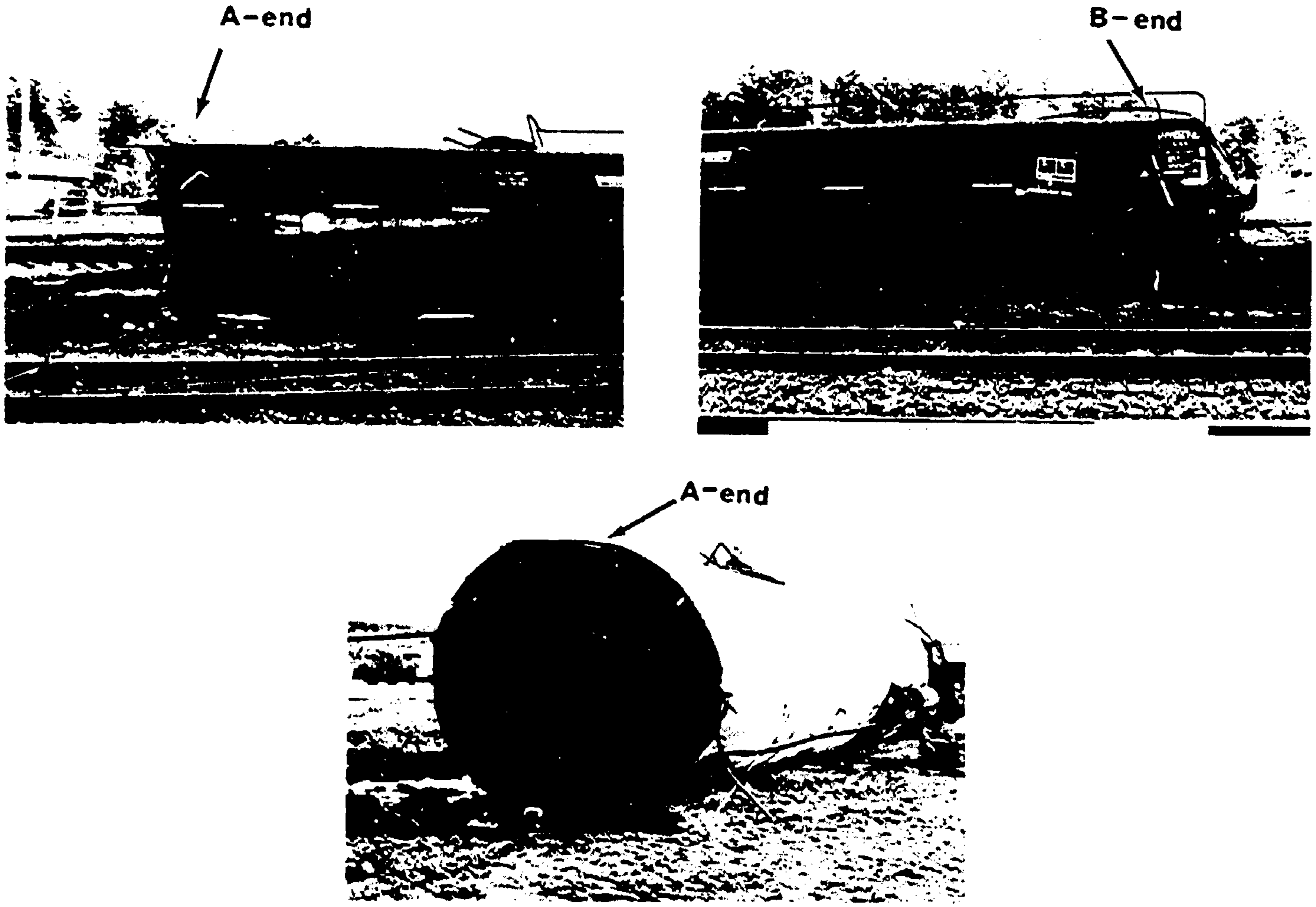


Figure 1—Side, A-end, and B-end views of CONX 9101.

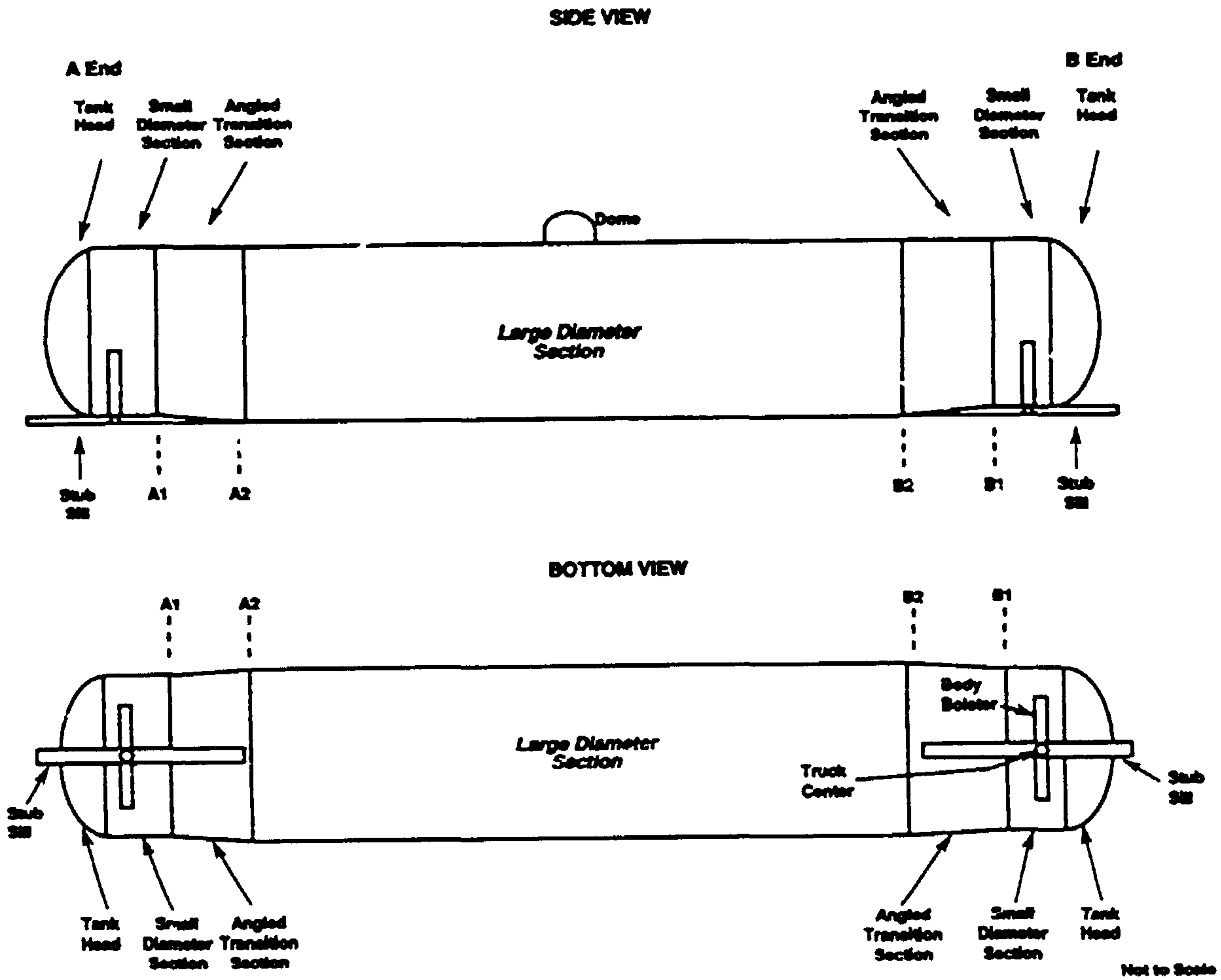


Figure 2—Bottom and side view diagrams of CONX 9101. A1, A2, B1, and B2 designate the circumferential welds in the tank at the A- and B-ends.

responsible for normal maintenance and the periodic testing and inspection of the tank car; Ferrellgas was responsible for maintaining the integrity of valves and fittings on the tank car.

According to the AAR Certificate of Construction, CONX 9101 was 1 of 35 tank cars in a series constructed in 1965 by GATC as DOT specification 112A340W tank cars. The 35 tank cars were originally leased to Monsanto Chemical Company with a reporting mark and numbers MCPX 33000 through 33034. Conoco assumed the lease from Monsanto for CONX 9101 and 30 of its sister tank cars[3] in 1979, after the 31 tank cars had been converted, with the addition of half head shields, thermal protection, and jackets, to DOT specification 112J340W tank cars. The tank cars were also assigned a new reporting mark and numbers as the CONX 9100 series.

CONX 9101 had a capacity of 32,878 gallons, and was equipped with running gear rated at 125 tons. The stub sill[4] was welded to an attachment pad on the small diameter section and the transition section. The inboard (toward the center of the tank) end of the stub sill terminated about 9 inches outboard (away from the center of the tank) of the circumferential weld joining the transition section and the large diameter section of the tank; and the attachment pad terminated between 5 and 6 inches outboard of the circumferential weld joining the transition section and the large diameter section of the tank (fig. 3). CONX 9101 was hydrostatically tested to the required test pressure of 340 psig in February 1983, and was not due for another hydrostatic test until 1993. (DOT requirements for hydrostatically testing tank cars are contained in Title 49 Code of Federal Regulations (CFR) Section 173.31(c) and are discussed later in this report.)

Description of Structural Failure.—The fracture and separation occurred along the outboard edge of the circumferential weld joining the large diameter section and the transition section for the A-end of the tank. Examination of the fracture surfaces on the tank shell disclosed a discolored crescent region that was about 21 inches long circumferentially and that was centered at the bottom centerline of the tank. Metallurgical examination at the Safety Board's materials laboratory showed that the discolored area of the fracture surface was extensively oxidized, which is indicative of long-term exposure to a corrosive medium and the presence of a preexisting crack. The extensive oxidization had obliterated the original fracture features. The preexisting crack was located longitudinally about 6 inches inboard (toward the center of the tank car) from the inboard end of the attachment pad for the stub sill (figs. 2 and 3) with initiation along the inside diameter surface of the tank at the weld/transition plate interface. Microscopic examination disclosed that the cracking occurred in the transition plate at and adjacent to the heat-affected zone from the weld. At its deepest point, the crack extended almost through the thickness of the transition plate (0.70 inch) before the circumferential separation occurred (fig. 4). Evidence indicated that the predominate growth of the crack was from the inside surface of the plate toward the outside surface. Within the fracture surface of the circumferential separation were many chevron markings in the overstress region, indicating that the fracture had stemmed from the preexist-

[3] The term "sister tank cars" describes a group of tank cars built to the same design.

[4] Unlike a continuous center sill, which extends the length of the tank and serves as a support for the tank, a stub sill assembly is welded to each end of the tank. Accordingly, the combined loads resulting from train action forces will be transmitted through the stub sill assembly on one end of the tank, through the tank, and through the stub sill assembly at the opposite end of the tank.

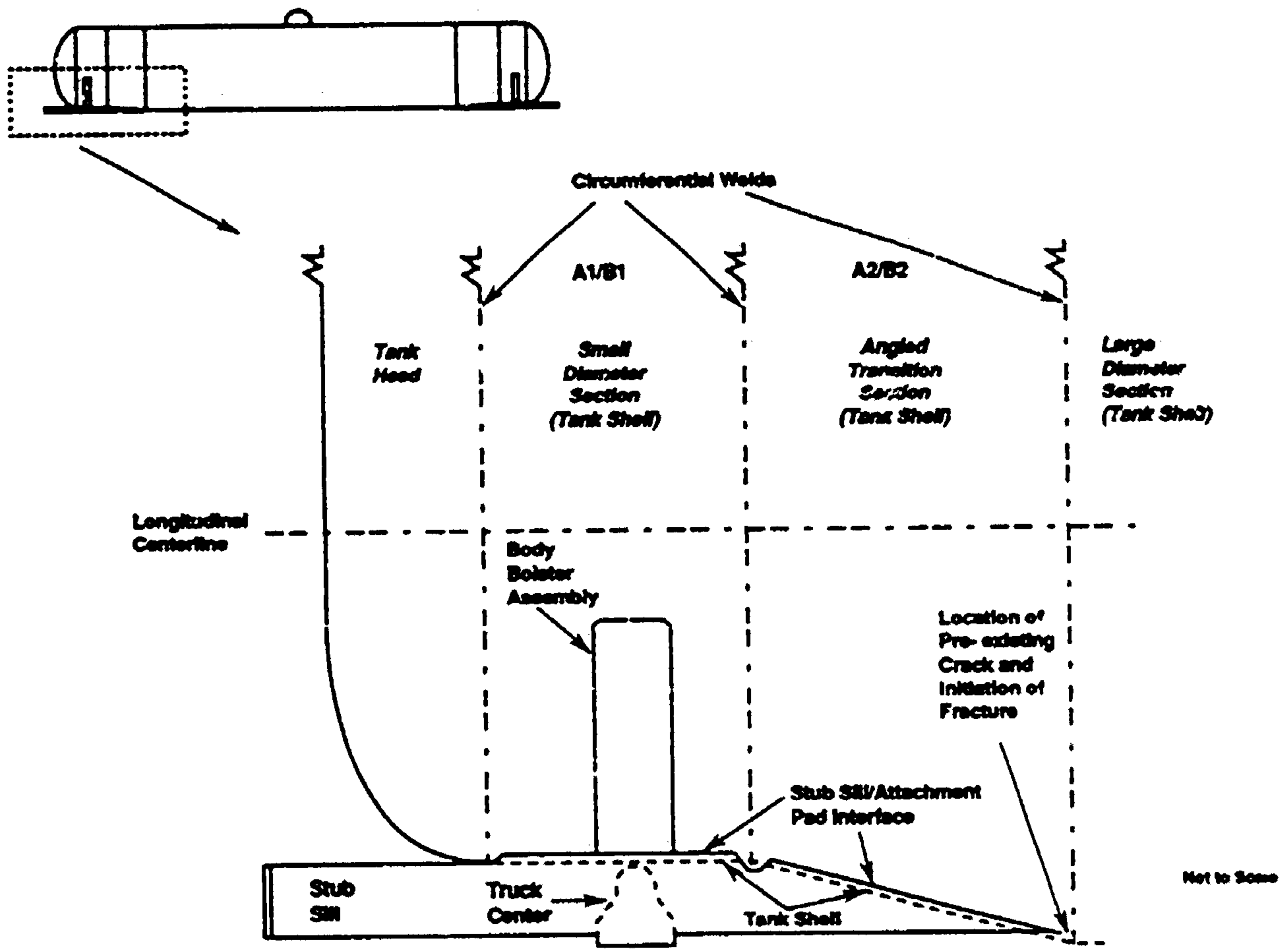


Figure 3—Side view of stub sill arrangement on CONX 9101.

ing crack. There were also numerous shallow cracks about 0.05 inch deep extending from the outside surface.

Fractographic examination of regions near the terminus of the preexisting crack disclosed indications of progressive fracture of the type resulting from fatigue. Because of the oxidation damage to the fracture surface, however, a positive identification of the mode of fracture could not be made. All other areas of the fracture surface outside of the preexisting crack region contained features that were typical of overstress breaks. Hardness tests and thickness measurements on sections of the tank plate near the fracture indicate the material was within the minimum specified design requirements.

A coupon[5] from the corresponding area of the large diameter/transition section interface at the B-end of the tank was also removed and examined for evidence of cracking. Visual and x-ray examination disclosed no cracks along the circumferential weld-to-plate interface.

Postaccident Actions.—On January 21, 1992, the AAR issued to member railroads and private tank car owners Early Warning Letter EW-123, which addressed the potential for failure of the CONX 9100 series of dual diameter tank cars. EW-123 directed that tank cars with a reporting mark and numbers CONX 9100 through 9133 be stopped immediately and scheduled for inspection. In a letter dated January 30, 1992, the FRA requested that Conoco withdraw those tank cars from interchange, and conduct nondestructive testing, including x-rays, of the circumferential welds between the transition section and larger diameter section at the bottom center of the tank car. Results of the testing were to be reported to the FRA. The FRA also requested notification prior to each tank car inspection and copies of records of all of the inspections. The proposed inspection procedures were reviewed and agreed upon by the FRA, Conoco, and the AAR.

In the meantime, GATC indicated that it had also built, in addition to the tank cars in the series that included CONX 9101, two other series of tank cars that were the same design as CONX 9101. One series included 30 tank cars that originally had a reporting mark and numbers CONX 9001 through 9031. However, at the time of the accident these tank cars were under the operation and control of Vista Chemical Company and had a reporting mark and numbers VICX 9001 through 9031. The second series included 50 cars that originally had a reporting mark and numbers GATX 30750 through 30799. Tank cars GATX 30785 through 30799, as the result of multiple changes in ownership, had been redesignated as VICX 9032 through 9046.[6] On February 10, 1992, the FRA requested that Vista and GATC, like Conoco, withdraw tank cars with these reporting marks and numbers from interchange, conduct nondestructive testing, and report the results to the FRA. Vista advised the FRA on February 14 that its dual diameter tank cars were to be cleaned and inspected as requested by the FRA. GATC also agreed to comply with the FRA's request. Further, on March 4, 1992, the AAR broadened EW-123 by directing that these additional dual diameter tank cars owned or operated by Vista and GATC also be stopped and removed from interchange.

By March 4, 1992, five other tank cars from these three series of tank cars that were still in service (5 of 108) had been inspected. Of the five other tank

[5] A coupon is a small section of the tank shell plate and weld that is cut from the tank and used for metallurgical examination.

[6] Of the 130 tank cars built to the same design as CONX 9101, only 109 of these tank cars, including CONX 9101, were in service at the time of the Dragon, Mississippi, accident.

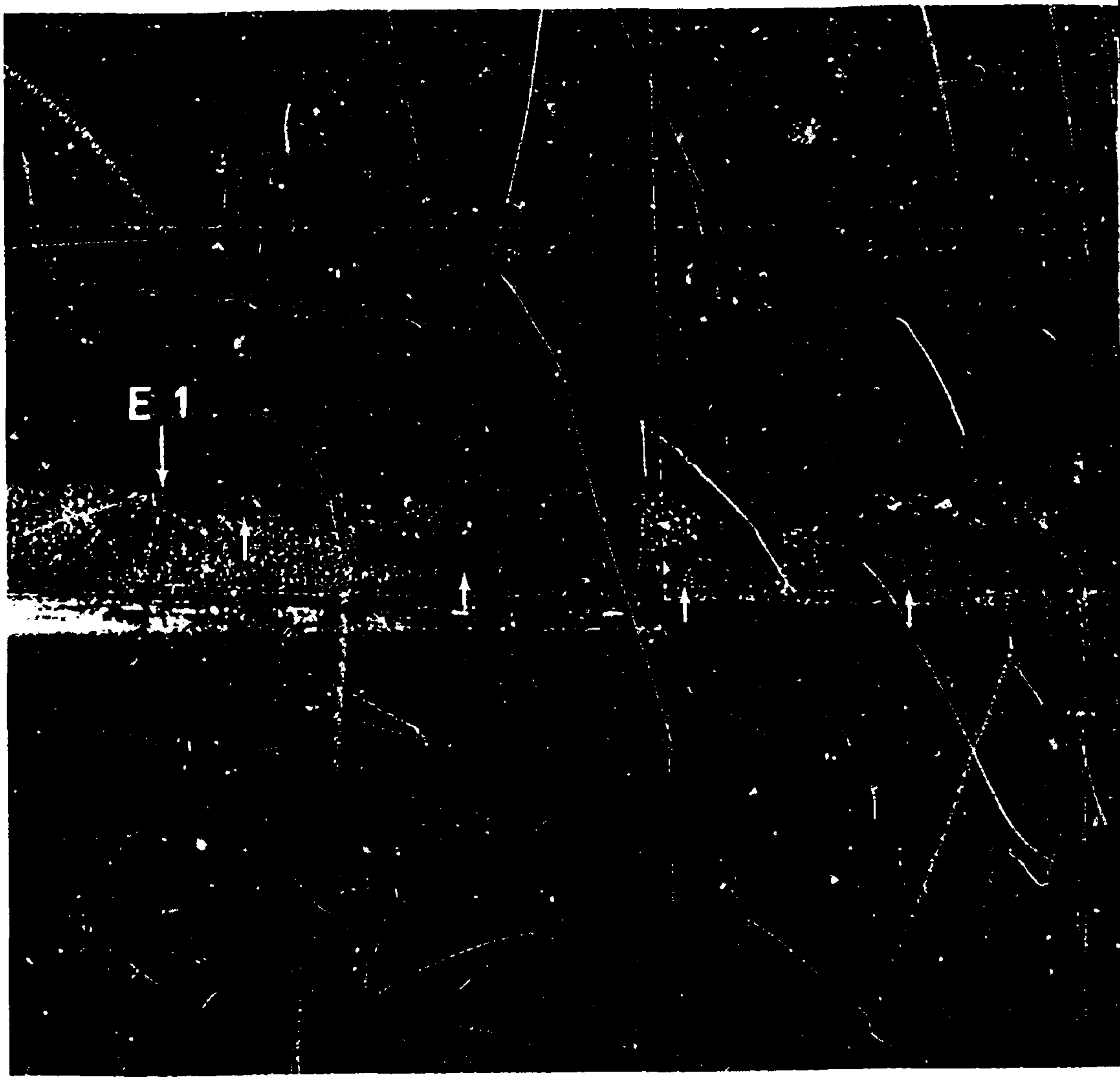
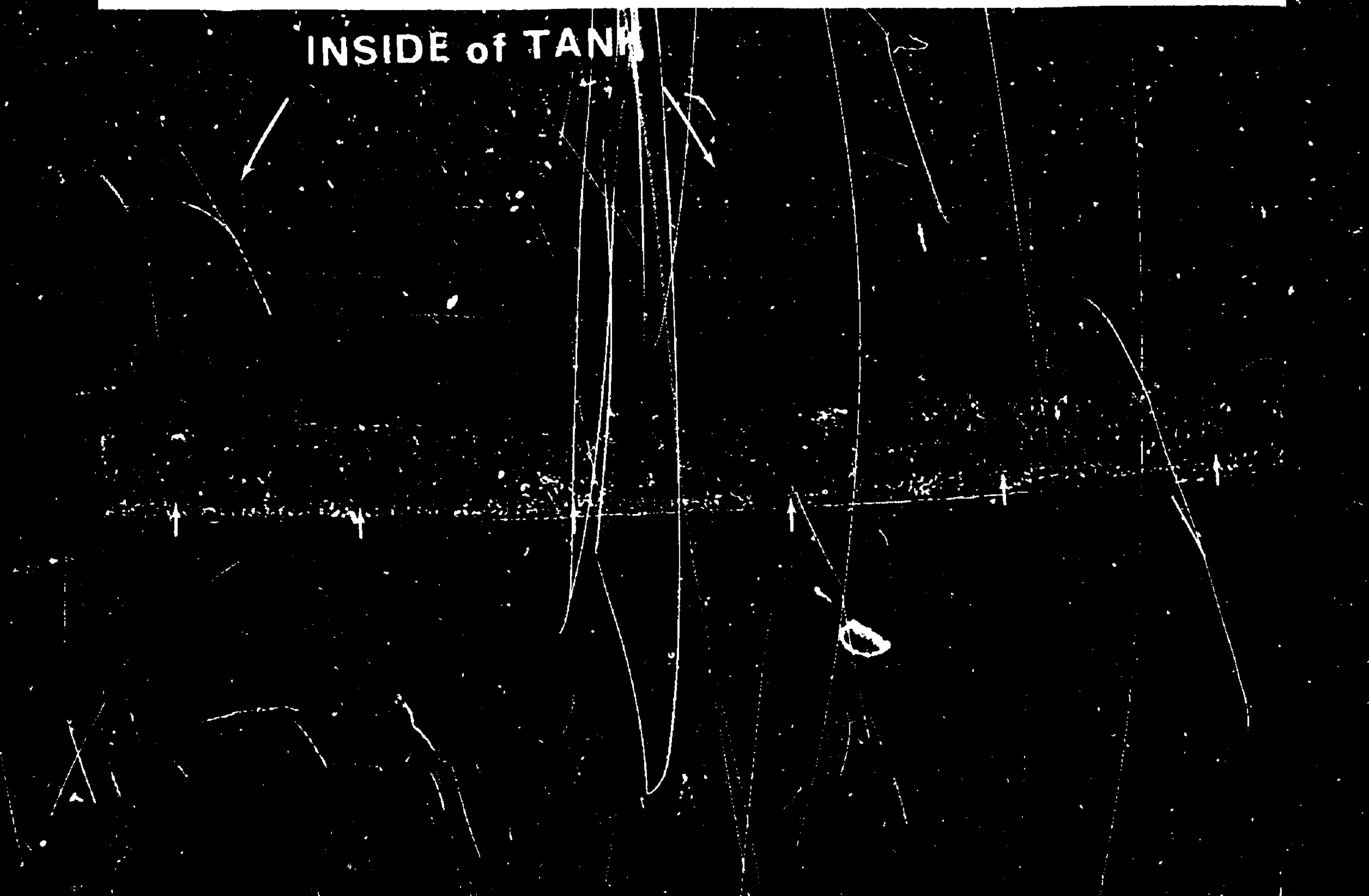
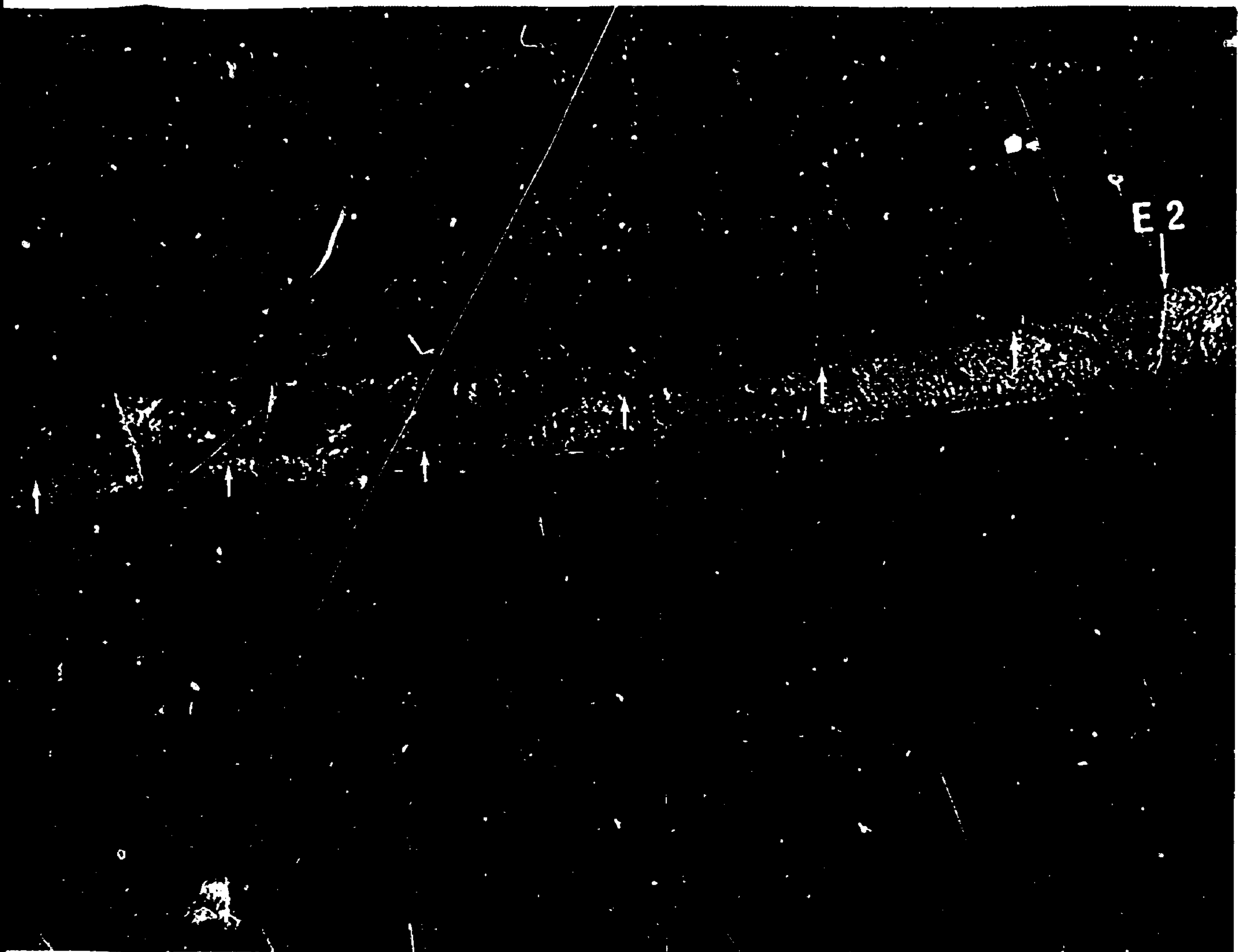


Figure 4—Surface of the crack in the transition plate at the A-end of CONX 9101. The white arrows mark the depth of the crack that propagated from the inside (top) surface to the outside (bottom) surface. E1 and E2 are the extremities of the crack on the inside diameter surface.


INSIDE of TANK


E 2

cars inspected, VICX 9019 was found by x-ray and confirmed by ultrasonic inspection to have a crack indication in the same area of the B-end as that found on the A-end of CONX 9101. A Safety Board metallurgist obtained specimens from the reported cracked area of the weld on March 9, 1992. Examination of these specimens disclosed that a crack about 12 inches long had initiated at the inside transition plate/weld bead interface in the same area as that of CONX 9101. The crack was about 0.06 inch deep, or nearly 9 percent of the tank plate thickness. Heavy oxidation had also obliterated the fracture features of the crack, but near its deepest point (terminus), the features showed indications of fatigue.

On March 11, 1992, the Safety Board was notified by Vista Chemical Company that three additional tank cars had been inspected (VICX 9008, VICX 9010, and VICX 9025). X-rays indicated that all three tank cars had circumferential cracks on both the A- and B-ends in the same locations ranging from 2 inches to 30 inches long. Because the severity and incidence of the cracks found in the Conoco and Vista tank cars raised concerns about the structural integrity of all dual diameter tank cars (about 5,500 tank cars of nine specific designs), the Safety Board issued a safety recommendation to the FRA on March 13, 1992, to:

> *R-92-7*
>
> Require owners and operators of dual diameter pressure tank cars to inspect by x-ray radiography and/or other appropriate means a representative sampling of their dual diameter tank cars for evidence of cracks and other serious defects in the circumferential welds between the transition and larger diameter tank shell plates. Based on these inspections, assess whether the total fleet of dual diameter pressure tank cars should be inspected immediately for evidence of cracking, and if periodic inspections should be required.

When the recommendation was issued, the FRA had begun to implement a formal program (described in the following section) to quickly test and inspect a representative sample of the dual diameter tank car fleet. Consequently, on April 29, 1992, the Safety Board classified Safety Recommendation R-92-7 "Open—Acceptable Response."

Inspection and Testing Program.—In a letter to the AAR dated March 16, 1992, the FRA cited the need to establish an aggressive program to sample a statistically valid number of dual diameter tank cars to assure the safety of each design of dual diameter tank car. The FRA requested that the AAR assist with the development and establishment of a program to inspect and test a representative sample of the dual diameter tank cars in the North American fleet to assure that the tank cars were safe.

In letters dated March 19 to Conoco, GATC, and Vista, the FRA formalized the inspection and testing procedures for the three series of tank cars that were of the same design as CONX 9101. These test procedures required x-ray examination of the A1 and B1 circumferential welds at the small diameter/transition section interface and the A2 and B2 circumferential welds at the large diameter/transition section interface (fig. 2). For each circumferential weld, x-ray examination was required for the area 2 inches on each side of the weld and at least 24 inches on each side of the longitudinal centerline of the tank. The FRA reported that by March 26, 38 tank cars of the same design as CONX 9101 and that were still in service had been inspected. Of the 38 tank cars inspected by x-ray, 22 were reported to have cracks in the circumferential welds, as found in CONX 9101, and other defects, such as weld inclusions and incomplete weld fusion that occur during the welding process. The cracks that were detected were estimated to range from 2 to 48 inches in length and up to 0.375 inch deep (about 58 percent of the thickness of the tank plate).

Based on its investigative findings, on April 2, the FRA issued Emergency Order 16, Notice No. 1,[7] that required all owners of dual diameter tank cars to develop a sampling plan for the inspection and testing of the dual diameter tanks cars in their fleets. The FRA required that the sampling plan must provide a 99-percent confidence level that no more than 1 percent of the dual diameter tank cars of any given design type would contain a structural imperfection in the critical welds at transition points. Any defects that were discovered were to be repaired before returning the tank car to service. Further, under the Emergency Order, the detection of a weld defect would subject all tank cars of that design to the inspection and testing procedures mandated in the order. The Emergency Order also prohibited the loading of or offering into transportation any dual diameter tank car before its owner had submitted a sampling plan. Tank cars included in the sampling plan were to be tested and inspected not later than June 3, 1992. The Emergency Order also instituted a continuing inspection program for all dual diameter tank cars built to the same design as any dual diameter tank car that was found to have a crack.

The FRA amended Emergency Order 16 on May 26, 1992, by issuing Notice No. 2 under the order.[8] The FRA noted that although 600 dual diameter tank cars had been inspected, (nearly 30 percent of the then estimated 2,100 tank cars scheduled for inspection under the owners' sampling plans), the owners would not inspect all of the targeted tank cars by June 3. The FRA consequently extended the inspection deadline to September 3, 1992, for owners who had inspected a minimum of 20 percent of the tank cars of a given design type by June 3. If less than 20 percent of the targeted tank cars of a given design type had been inspected by June 3, all tank cars of that design would be prohibited from remaining in service. The FRA indicated in a letter to the Safety Board dated July 28, 1992, that all owners of dual diameter tank cars complied with the June 3 deadline except the owner of one design type predominantly operating in Mexico.

Through the Emergency Order, nine specific designs of dual diameter tank cars were identified, with populations ranging from 100 to 1,970 tank cars. In its second amendment to the Emergency Order, Notice No. 3 issued on August 27, 1992,[9] the FRA noted that the original criteria for establishing the number of tank cars to be inspected by each owner placed a disproportionate burden on owners with small fleets of a specific design. Consequently, the FRA determined that owners with fleets of 500 or fewer dual diameter tank cars of a specific design type would satisfy the Emergency Order by inspecting 50 percent of the population of that design type.

Test Results of Dual Diameter Tank Cars.—As of September 29, 1992, 108 tank cars of the same design as CONX 9101 were tested and inspected. Of these 108 tank cars, 40 tank cars were reported to have cracks in the circumferential welds that were estimated through x-ray and ultrasonic inspection to be between 1 inch and 58 inches in length. The cracks in 21 of these 40 tank cars were reported to exceed 18 inches in length. The depth of the cracks, as reported, were between 0.125 inch and 0.625 inch

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[7] Federal Register, Vol. 57, No. 67, dated April 7, 1992, page 11900.

[8] Federal Register, Vol. 57, No. 101, dated May 26, 1992, page 22014.

[9] Federal Register, Vol. 57, No. 171, dated September 2, 1992, page 40245.

deep. (The measured thickness of the tank shell plate removed from CONX 9101 was 0.70 inch.) Of these 40 tank cars, 13 tank cars had been tested under DOT's periodic testing and inspection requirements during 1991 and 1992; and 25 of the 40 tank cars had been tested and inspected since 1988. No circumferential cracks or other deficiencies were noted during these tests and inspections.

The testing of the representative samples of the 5,500 dual diameter tank car fleet is continuing. The FRA indicated that as of November 30, 1992, 2,294 tank cars (104 percent of the 2,207 tank cars initially included in the test population) had been tested and inspected in accordance with Emergency Order 16. Based on the inspections performed as of November 30, the only design of dual diameter tank car that has been withdrawn from service under the Emergency Order because of fatigue cracking or other critical deficiencies along the circumferential welds is the one design of the GATC-built dual diameter tank car that failed in Dragon, Mississippi. According to the AAR and the FRA, 17 dual diameter tank cars designed and built by Union were withdrawn from service under Notice 3 to the Emergency Order because inspections of all tank cars in the test population for this design were not completed. Although the tank car owners had previously inspected only 160 of a minimum of 177 tank cars, the additional 17 tank cars were withdrawn from service until they were inspected. Like the other 160 tank cars, no critical defects were detected in these 17 tank cars.

However, Conoco believes that similar cracking has also occurred in about 10 of its dual diameter tank cars of a second design type built by GATC. X-ray inspection detected a crack in the heat-affected zone in the transition shell plate adjacent to a circumferential weld of tank car CONX 9387. The FRA and GATC each removed coupons from this tank car and performed their own, independent metallurgical examinations. The conclusions from both examinations indicated that the crack in the test coupons was caused by weld shrinkage from cooling at the time the tank was manufactured, and that the crack had not propagated by fatigue. Conoco believes these cracks may be caused by stress and would propagate. Therefore, Conoco has voluntarily withdrawn these tank cars from service pending the completion of its own metallurgical examination of the cracks detected in these tank cars.

Of the 1,970 tank cars of this design in service, 514 tank cars, including the 10 Conoco tank cars, were inspected under the FRA's Emergency Order. Other than the cracks detected in the Conoco cars, no defects have been detected in tank cars of this design.

Nonpressure Tank Cars

Accident at Kettle Falls, Washington.—About 6:10 a.m. local time on March 25, 1992, tank car UTLX 13835, a nonpressure tank car,[10] cracked along a circumferential weld at the bottom center of the tank, resulting in the release of 13,000 gallons of concentrated sulfuric acid, which is regulated as a corrosive liquid by the DOT (fig. 5). The crack was first detected when a brakeman for the Burlington Northern Railroad was sprayed by the escaping acid as he conducted a walk-by inspection of Burlington Northern train 1-606-25 as it was departing south from the depot in Kettle Falls. The train was stopped, and UTLX 13835 was removed from the train and moved onto a siding and over a concrete pit. Of the 13,000 gallons of sulfuric acid initially in

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[10] Nonpressure tank cars are those with test pressures not exceeding 100 psig. Pressure tank cars have test pressures from 100 psig to 600 psig.

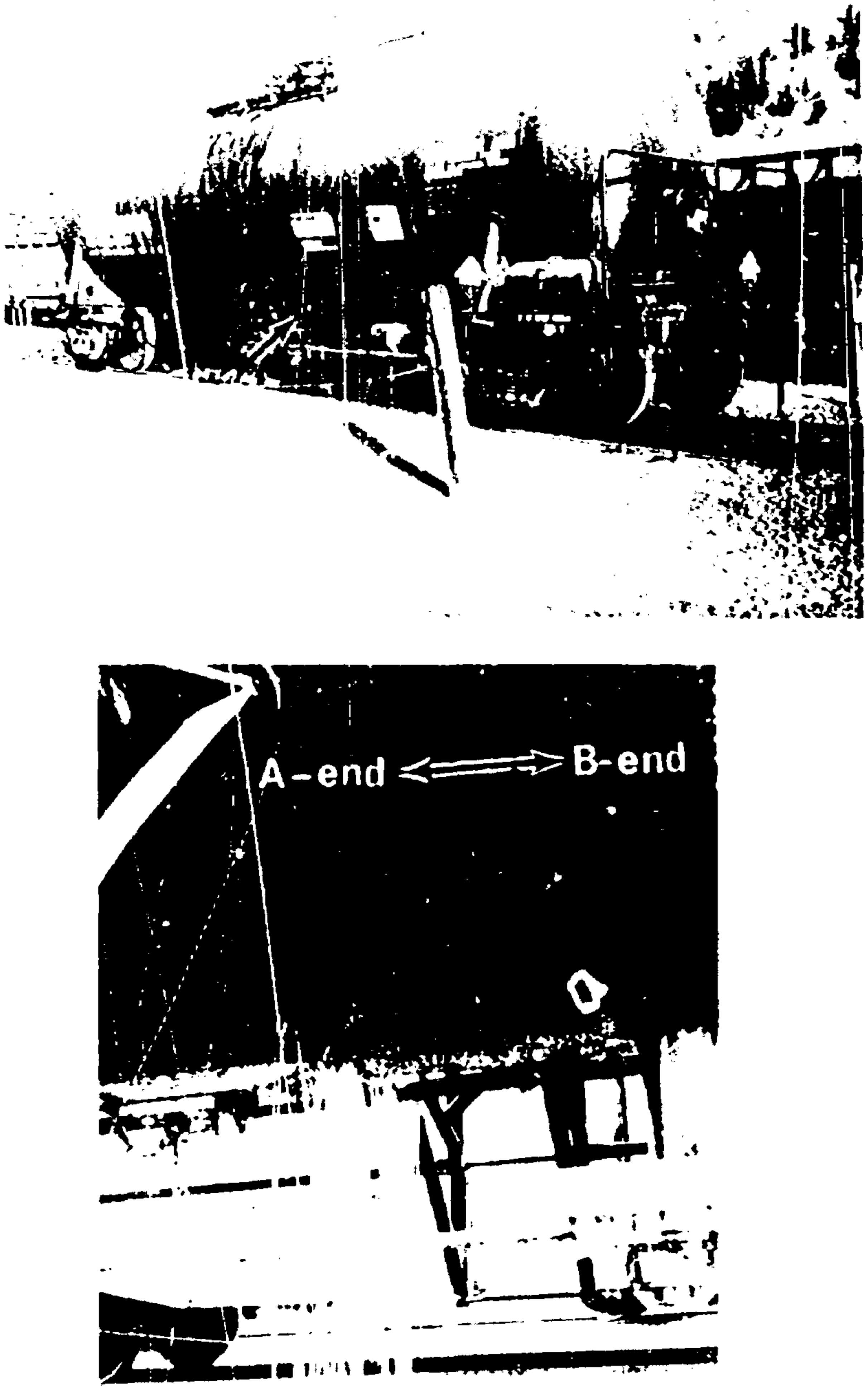


Figure 5—UTLX 13835 with acid leaking from the bottom center of the tank car. (Photographs courtesy of the Federal Railroad Administration.)

the tank car, between 9,000 and 10,000 gallons were recovered from the concrete pit and from a portable collection pool that was placed under the leak. During a subsequent examination of the rails and the track bed, an FRA inspector found evidence of leakage from 0.8 mile north of the depot in Kettle Falls to the depot itself.

The brakeman, who was sprayed by the sulfuric acid, was immediately hosed down with water; he received only minor injuries from the sulfuric acid. There was no evacuation. Environmental damage and clean-up costs were estimated at $31,000 by Imperial West Chemical Company and the Burlington Northern.

The tank car was the 57th car of a 107-car train with 5 locomotives. The tank car had been loaded on March 24, 1992, at the Imperial West Chemical Company facility in Northport, Washington, about 34 miles north of Kettle Falls, and upon movement to Kettle Falls, had been placed in train 1-606-25.

Tank Car Information.—UTLX 13835 was a single-compartment DOT specification 111A100W2 tank car with a capacity of 13,677 gallons. The tank car was one of a series of five tank cars (reporting mark and numbers UTLX 13833 to 13837) that were built in 1981 by Union, which also owns the five tank cars. According to Union records, the tank car has a sprayed-on and baked phenolic lining to protect the steel tank wall from corrosive cargoes. A visual inspection of the tank's interior and exterior and a hydrostatic test of UTLX 13835 had been performed at the Union tank car maintenance facility in El Segundo, California, on February 20, 1992. During the hydrostatic test, the tank was filled with water and internal tank pressure was maintained at 100 psig for 1 hour. No leaks or other problems were noted during the visual inspection and hydrostatic test. The sulfuric acid was loaded into the tank car at Northport, Washington, on March 24 and was the first load for the tank car since it had been visually inspected and hydrostatically tested.

When UTLX 13835 and its four sister tank cars were originally constructed, an oval opening measuring 12 3/4 inches by 6 7/8 inches was cut out of the bottom center of the car, and a rectangular cover for the sump was welded over that opening (fig. 6). Although the oval opening did not overlap the circumferential weld at the bottom center of the tank, the rectangular sump cover was welded across the circumferential weld. Each tank car also had bottom shell reinforcement plates along the bottom of the tank car from each end toward the center of the car and extending to the sump cover.

The original lessee of the five tank cars, the Degussa Corporation, requested that Union replace the original rectangular sump cover with a round sump cover before the tank cars were placed into service. To complete this modification, Union cut out the rectangular sump cover; repaired the original oval opening by welding a piece of plate of the same grade of steel and thickness as the tank shell to fill the opening; and cut a new 14-inch-diameter hole, which crossed the circumferential weld at the center of the tank, in the bottom of each tank car. Union then welded a 17-inch-diameter sump cover over this opening and cut or extended the reinforcement plates to butt with the circular sump cover (fig. 6). The modifications to all five tank cars were completed in 1982.

Union reassumed control of the five tank cars in 1986 and replaced the circular sump with a rectangular sump that was similar to that originally installed. To restore each tank car to its original configuration, Union removed the circular sump cover, repaired the 14-inch diameter hole in the tank, cut a new oval opening in the tank wall for the new sump, and then welded the rectangular sump cover across the circumferential weld at the bottom center of the tank car.

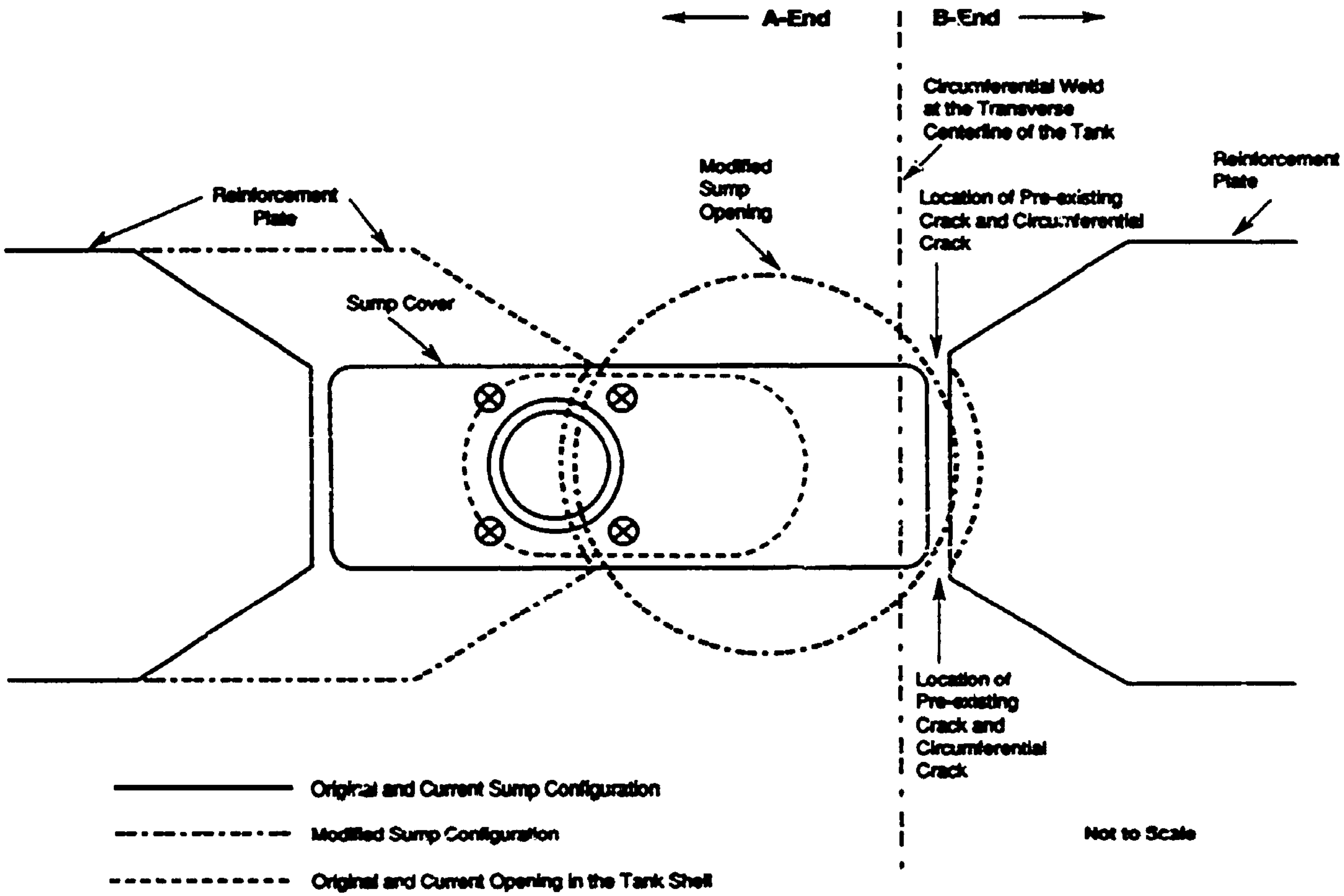


Figure 6—Past and current configurations of the sump area on UTLX 13835.

Metallurgical Testing.—On April 9, 1992, a Safety Board metallurgist examined UTLX 13835 at the Imperial West Chemical Company facilities in Spokane, Washington. The crack was located at the bottom center of the tank in the heat-affected zone adjacent to the circumferential weld (fig. 6) and on the B-end side of the weld. Looking toward the A-end of the tank, the 34 1/2-inch crack extended about 14 inches left and about 20 1/2 inches right of the bottom center of the tank.

The interior of the tank was also entered and examined. There was no visible evidence of deterioration of the protective lining other than cracks in the lining that were parallel to and along the crack in the tank shell.

Following the examination of the tank, a coupon that included the circumferential crack and adjacent shell plate was removed from the tank car. Upon the removal of the coupon at the site, it was then cut to expose the majority of the fracture surface of the crack for immediate inspection. The majority of the exposed crack contained features representative of an overstress separation stemming from the bottom central portion of the tank. Fracture chevron markings indicated that the overstress originated at two locations: one on either side of a large fatigue crack and near the corners of the sump cover and the reinforcement plate (figs. 6 and 7). The region with the large fatigue crack had initiated from multiple sites along the exterior bottom surface of the tank with crack propagation toward the interior surface. The fatigue crack extended about 6 inches circumferentially along the tank bottom and more than halfway through the tank wall at its maximum penetration. A second and smaller fatigue crack was also noted along the exterior bottom of the tank at one of the origins for the overstress separation. The second fatigue crack extended about 3/4 inch circumferentially along the tank bottom and penetrated only about one-sixth of the thickness of the tank wall. All other features on the fracture surface were typical of overstress separations.

Further metallurgical testing and examination was conducted at the Safety Board's materials laboratory. The large fatigue crack was located at the base juncture of two separate fillet welds that attached the sump cover and the reinforcement plate to the underside of the tank. These fillet welds resulted in a deep notch between the sump cover and the reinforcement plate. Union's design drawings for the original configuration and the most current modification showed that the area between the sump cover and the reinforcement plate was to be groove welded (filled in with weld material flush to the lower adjoining surfaces of the sump cover and the reinforcement plate) and was not to remain fillet welded (fig. 8).

Hardness tests indicated that all materials were within the specified tensile strength requirements. The specified thicknesses of the tank shell and the tank inserts used to fill the holes in the tank shell were 5/8 (0.625) inch. The measured thicknesses of the tank shell and tank insert away from the crack plane were about 0.61 and 0.62 inches, respectively. (The minimum thickness of the tank shell required by 49 CFR 179.200-6 for this tank car is about 1/2 (0.50) inch.) Along the crack plane, the thickness of the tank insert and the apex of the notch caused by the fillet welds was about 0.52 inches. Localized yielding along the bottom of the tank accounted for some of the reduction in thickness. The original thickness through the crack plane was estimated to be 0.58 inches, after adjusting for the reduction in thickness from the localized yielding.

Inspection and Testing of Sister Tank Cars.—On April 26, 1992, one of the sister tank cars, UTLX 13836, was examined by the Safety Board at Union's maintenance facility in El Segundo, California. The tank car had the prescribed groove welds, rather than fillet welds, between the sump cover and the

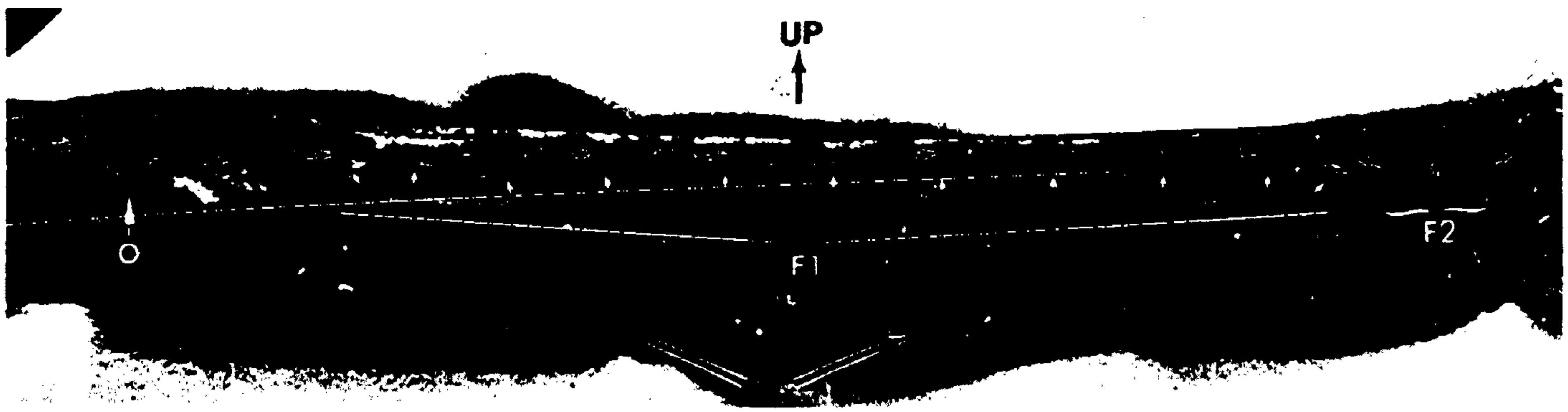
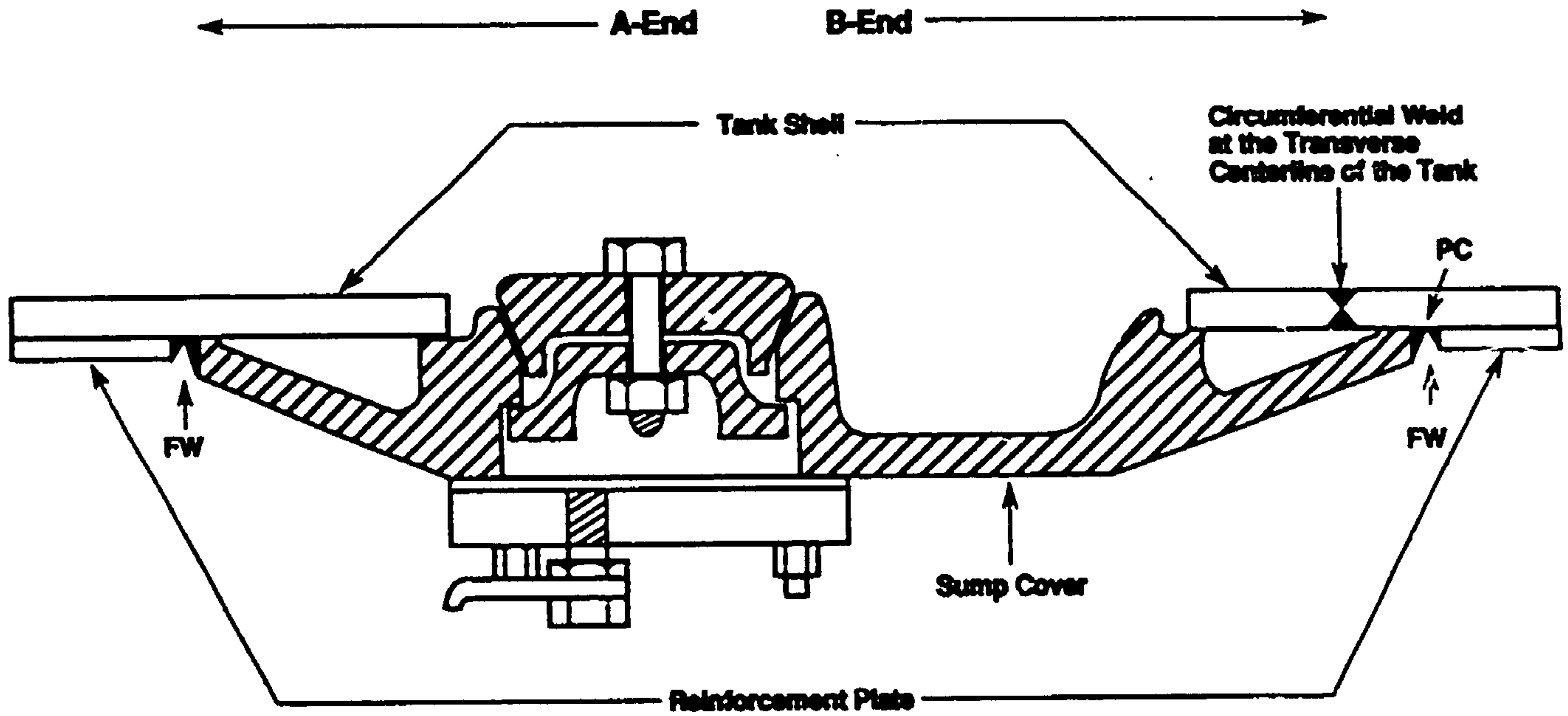


Figure 7—Fracture surface from UTLX 13635. The large fatigue crack (F1) is marked by the bracket and white arrows. The smaller fatigue crack (F2) and the marked location (O) are the origins of the overstress. The black and white arrows indicate the directions of propagation of the fracture. The reinforcement plate (RC) is at the bottom.



FW – Fillet welds at locations that were required to have groove welds.

PC – Location of preexisting crack and origin of circumferential crack.

Not to Scale

Figure 8—Cross sectional view of the sump cover on UTLX 13835. The design drawings indicated that the areas with fillet welds (FW) were to have groove welds. PC indicates the location of the preexisting crack and origin of the circumferential crack.

bottom shell reinforcement plate. On June 2, 1992, the three remaining sister cars (UTLX 13833, UTLX 13834, and UTLX 13837) were also examined by Union and were found to have groove welds between the sump cover and the bottom shell reinforcement plates.

The FRA directed Union to conduct nondestructive testing on the four sister tank cars that were built to the same design and were similarly modified as UTLX 13835. In a letter dated April 10, 1992, the FRA requested that Union remove these tank cars from service until each tank car was internally and externally inspected for defects at an AAR-certified tank car repair shop. In a letter dated May 5, the FRA finalized the testing procedures for these tank cars. Under these procedures, all welds on each tank car were to be visually examined. Further, the FRA stipulated that one of two nondestructive testing methods, either magnetic particle examination or ultrasonic examination, was acceptable to inspect and test the welds for the sump cover, the circumferential welds in this area, and any other welds that had been made during the modification of the tank cars. The FRA also required ultrasonic measurement of the thickness of each defect detected. The FRA directed Union to provide a record of the testing results within 30 days of the completion of the tests on each tank car.

Union reported the test results to the FRA in a letter dated August 24, 1992, and included copies of the inspection reports on UTLX 13835 and its four sister tank cars. There were no deficient welds reported for tank cars UTLX 13834, 13836, or 13837. Union reported that there were "some slight cracks" in the welds on the A-end of UTLX 13833, including a 6-inch-long crack with a depth less than 3/16 inch. Union attributed these cracks to be the result of poor weld quality. Union also reported cracks in the welds between the sump cover and the reinforcement plate on the opposite side from the circumferential crack in UTLX 13835. Union indicated that because both sides of the sump cover had incorrect welds, the development of cracks in the welds on the opposite end of the cover plate from the crack in the tank at the circumferential weld was to be expected.

Stub Sill Attachment Pads

Background.—Since 1985, several incidents involving many classes of DOT specification tank cars have occurred and have been attributed to structural failures in the welds between the stub sill and the attachment pad, or between the attachment pad and the tank (fig. 9). Although none of these failures resulted in a derailment, some incidents resulted in the release of cargo.

In a letter dated May 13, 1985, the FRA requested ACF Industries, Incorporated (ACF), to furnish information on a series of dual diameter tank cars operating in Canada that were found to have cracks in the welds connecting the cradle pad to the tank. In a letter dated June 12, 1985, the ACF responded that the cracks on that series of 1,296 tank cars may propagate into the stub sill area under certain heavy impacts or derailment situations. However, none of the cracks resulted in the complete separation of the stub sill from the tank car. ACF also indicated it had initiated a program to inspect and repair all tank cars in this series. The FRA and Transport Canada[11] were advised of ACF's plans and monitored the progress of the program. All tank cars were inspected and repaired by April 30, 1986.

[11] Transport Canada is the Canadian government's counterpart to the U. S. Department of Transportation.

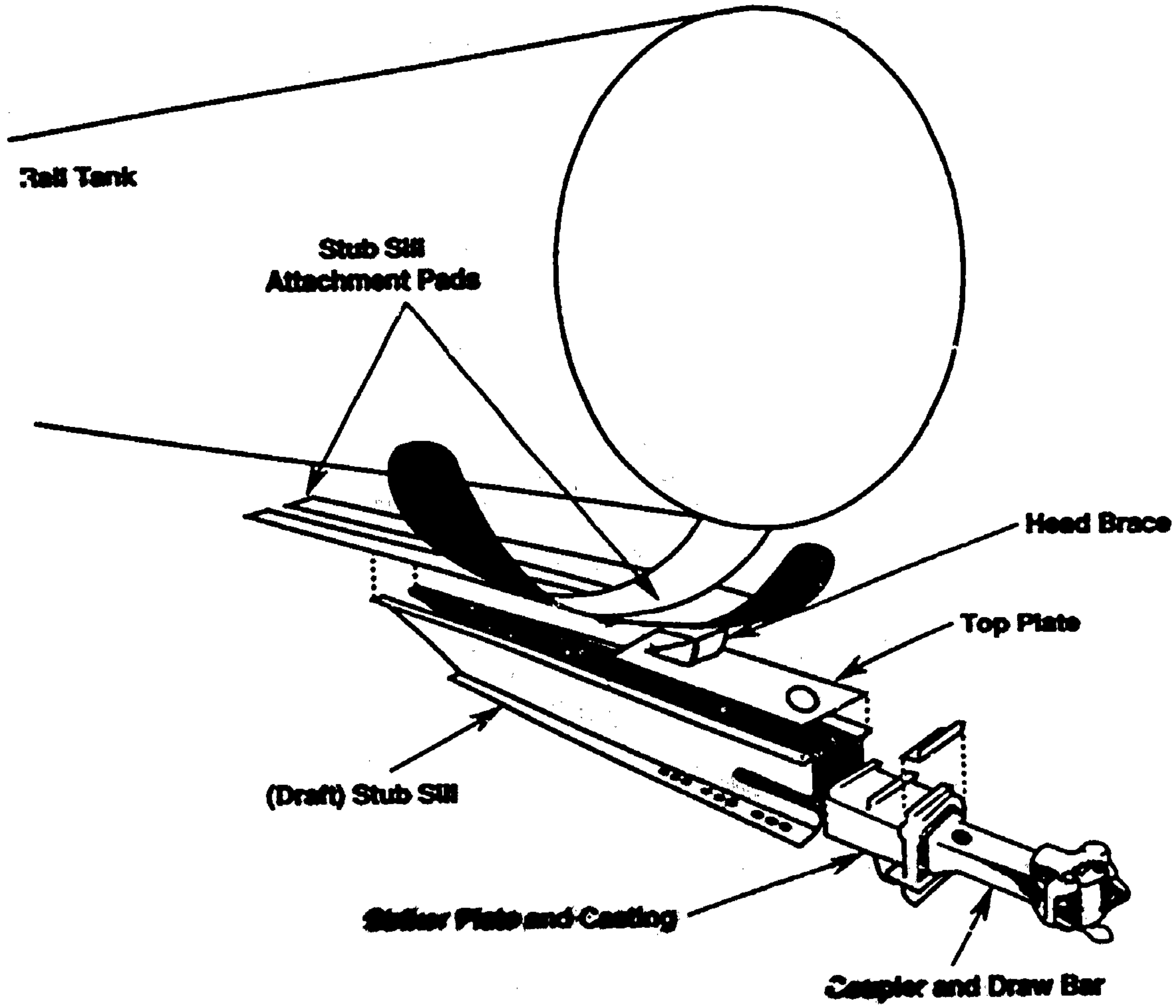


Figure [illegible]—Configuration of typical stub sill and body bolster. (Adapted from a drawing with copyright held by General American Transportation Corporation. Used with permission.)

On February 4, 1985, at the Conrail receiving yard in Elkhart, Indiana, a DOT specification 112S400W tank car, NATX 9408, released anhydrous hydrogen fluoride, an extremely corrosive and toxic liquid; this release resulted in the evacuation of 1,500 people from a residential area next to the yard. The Safety Board's investigation of this accident[12] determined that the release occurred through a 10-inch crack in the head on the B-end. Metallurgical examination of the crack at the Safety Board's materials laboratory disclosed that the crack appeared to have been the result of a single force impinging on a preexisting crack in the plate of the tank head. The preexisting crack initiated at a weld undercut[13] on the external head-to-stub sill weld. The crack followed this weld before propagating into the tank head. The head-to-stub sill welds on a sister tank car, NATX 9405, were also examined. A 1-inch crack that had penetrated into but not through the tank head was detected at one end.

On March 30, 1990, the stub sill on a Union-built tank car, UTLX 90482, failed while the tank car was part of a Kansas City Southern freight train en route from Lake Charles, Louisiana, to Shreveport, Louisiana. UTLX 90482 was a DOT specification 105J300W tank car containing vinyl chloride, a flammable gas. The failure of the stub sill resulted in a separation between cars within the train and the application of the train's emergency brakes. There was no release of the vinyl chloride or evacuation.

In a letter dated April 2, 1990, the FRA requested that Union provide information about the incident involving UTLX 90482 and Union's plans to inspect other tank cars of a similar design. The FRA also requested that Union provide details about the failure of a stub sill that had previously occurred in August 1988 on a another Union-built tank car, UTLX 98228. In a May 4 response to the FRA, Union noted that a fillet weld between the stub sill and head brace on UTLX 90482 did not have the proper penetration. Union attributed the deficient weld to poor workmanship and considered the incident to be an isolated case. Union also noted that the stub sills on three other Union-built DOT specification 105J300W tank cars (UTLX 98228, 98263, and 98197) had also failed between August 1985 and May 1989. Union stated that the design of the stub sill and the head brace on these four tank cars was a standard design that Union had used on more than 20,000 tank cars since the late 1960s. Union was unable to provide details about the stub sill failures and the repairs made to these three tank cars. The four tank cars were built in 1979 and 1980.

In its May 4 response, Union also stated that it had begun to inspect the welds on the stub sill assemblies of the other 157 tank cars that were built under the same construction certificate as the four failed tank cars. The welds were to be tested by dye penetrant. Of the 15 tank cars that had been inspected by the time of the May 4 response, Union noted that cracks ranging from 6 inches to 17 inches in length had been found in the head-to-stub sill welds on 3 tank cars, and smaller cracks ranging in length from 1 inch to 2 1/2 inches had been found at eight other "locations."

On June 13, 1990, Union informed the FRA of an additional stub sill failure on another DOT specification 105J300W tank car, UTLX 90776, that was

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[12] National Transportation Safety Board. 1985. Anhydrous hydrogen fluoride release from NATX 9408, train No. BNEL3Y at Conrail's receiving yard, Elkhart, Indiana, on February 4, 1985. Hazardous Materials Accident Report NTSB/HZM-85/03. Washington, DC.

[13] A defect that occurs during welding and leaves a groove melted into the base metal adjacent to the weld.

transporting vinyl chloride. The incident occurred on May 24, 1990, in the Burlington Northern Railroad yard in Tulsa, Oklahoma. The stub sill on the A-end of UTLX 90776 broke and separated from the tank car without loss of product as the tank car was being moved within the yard. Union's inspection of the tank car following the incident indicated that the weld between the head brace and the tank head reinforcing plate had been "broken for some time," and cracks had propagated through the stub sill assembly until separation occurred. According to Union, the tank car had been previously repaired in 1988 and again in 1989 because of derailment damage to the stub sill assembly at the A-end. With the concurrence of the FRA, Union agreed to conduct the same tests and inspections on the 48 sister cars to ULTX 90776 that were being conducted for the previous group of 157 tank cars.

On July 7, 1990, tank car UTLX 94576, which was also loaded with vinyl chloride, sustained a structural failure of the stub sill at the Conrail yard in Enola, Pennsylvania. In a letter dated July 26, 1990, the FRA requested Union to provide details of this latest incident. The FRA also expressed its concern about the stub sill problems, and the need to formalize an accelerated program to inspect and repair those Union tank cars with stub sill assemblies of the same design that had failed on tank cars UTLX 90482 and UTLX 90776. The FRA requested that Union complete its inspections within 60 days. On the same date, the FRA also recommended to the AAR that it work with the tank car manufacturers, owners, and users to develop and implement an industry-wide program to inspect all tank cars with stub sill assemblies within 5 years. The FRA further recommended that dye penetrant testing and fiber optic technology or equivalent technology be used to inspect the welds in stub sill assemblies. In response to the concerns of the FRA, the AAR Tank Car Committee directed its Acoustic Emissions Inspection Task Force to evaluate the feasibility of inspecting the stub sill area and its attachments using acoustic emissions techniques. The Committee also directed a second working group to develop requirements for the examination and repair of damaged stub sills.

Failures on Canadian-Built Tank Cars.—Between January and May 1991, four DOT specification 112J340W tank cars in Canada experienced complete separations of their stub sills at welds between the stub sill and attachment pads on the tank. The four tank cars, which were used for the transportation of liquefied petroleum gas, were built by Canadian manufacturers: Hawker-Siddley, Canada Ltd.; and Davie Shipbuilding, Ltd. The stub sills on the four tank cars were of the same design. After the failure of the second tank car, DCTX 33181, in February 1991, Transport Canada prohibited Canadian railroads from transporting the 10 tank cars in this series (DCTX 33180 to 33189) until the attachment welds of the stub sill had been inspected and, if necessary, repaired. Of seven tank cars in the series that were inspected on April 23, 1991, five of the tank cars were found to have cracks in various welds for the stub sill assembly.

On May 1, 1991, Transport Canada issued an order to the Canadian railroads regarding 86 tank cars with similarly designed stub sills and having reporting marks DCTX or NCTX and numbers from 33096 to 33189. Under this order, those tank cars were to be moved to a repair facility and prohibited from further movement until an inspection of the stub sill was made and repairs, if necessary, were completed. On May 2, the AAR issued Early Warning Letter EW-121 directing that the tank cars identified by Transport Canada be stopped, and that the stub sills be inspected for evidence of cracks at or near the sill-to-tank attachment pad. Cracks or serious manufacturing defects were found in the stub sill area of more than 80 percent of the tank cars inspected.

The AAR then issued EW-122 on August 9, 1991, based on the results of the inspections of the Canadian-built tank cars conducted under EW-121. EW-122 directed inspections of an additional 143 tank cars with stub sills of the same design as the tank cars covered by the previous early warning letter.

On August 19, 1991, the AAR issued Maintenance Advisory Letter (MA-04), pursuant to direction from the FRA. The maintenance advisory letter covered 100 randomly selected tank cars from 2,600 tank cars that were built in the United States by North American Tank Car Corporation (NACCO) and had the same stub sill design as the Canadian-built tank cars. In Circular Letter c-7719 dated October 4, 1991, the AAR reported the inspection results to the FRA. From the 100 tank cars inspected, the AAR found:

- 32 cracked seal welds;
- 15 other seal welds with defects;
- 1 cracked butt weld; and
- 6 cars requiring repairs under FRA car safety standards.

The remainder of the 2,600 NACCO-built tank cars, an additional 5,000 tank cars built in the United States by Trinity Industries and requiring head brace modifications, and about 429 Union-built tank cars that remained to be inspected under previous directives were designated as "Priority II" class tank cars under the short-term fleetwide inspection program described in the following section of this report.

Fleetwide Inspection and Testing Program.—Because of the stub sill failures that occurred in Canada, the FRA and Transport Canada sent a joint letter to the AAR on June 13, 1991, expressing their concerns about the limited progress of the AAR's Tank Car Committee on the issue of stub sill failures. The FRA and Transport Canada proposed that an agreement on the procedures, testing methods, and identification of defects be reached during the AAR's Tank Car Committee meetings scheduled for July 1991. The FRA also restated its goal to have the stub sill assemblies on all tank cars, including those in nonhazardous materials service, inspected and repaired within 5 years.[14]

At the July meeting of the Tank Car Committee and by a joint letter to the AAR dated July 31, 1991, the FRA and Transport Canada requested, as a short-term measure, that a representative sample of 1,100 tank cars encompassing all stub sill designs be inspected by December 31, 1991. The FRA and Transport Canada further requested that the Tank Car Committee provide the inspection data and a theoretical analysis of the design integrity of stub sills in service. The AAR issued Circular Letter c-7697 on August 9, 1991, that implemented the sample inspection plan proposed by the FRA and Transport Canada. Under the program to inspect stub sill assemblies, tank cars that were in repair shops because of accident or derailment damage (designated as Priority I) had to be inspected before they could be returned to service. Tank cars that had been identified through previous AAR early warning letters or maintenance advisories as having a history of defects or cracks (designated as Priority II) had to be inspected within the 3-year time frame established by the early warning letters, maintenance advisories, or the Tank Car Committee. The program also implemented the inspection of the stub sills on 1,100 randomly selected tank cars (designated as Priority III) with a completion date of December 31, 1991. According to the AAR, data from

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[14] The FRA estimates that 120,000 tank cars will be subject to these inspections.

the completed inspections of the 1,100 randomly selected tank cars indicated that cracking in the stub sills may exist in the attachment welds on a "significant" number of tank cars, and that the potential problems are not specific to any particular stub sill design.

The AAR, with the assistance of the RPI and the concurrence of the FRA, developed a long-range inspection plan that was implemented through the AAR's O&M [Operations and Maintenance] Circular No. 1 dated July 17, 1992. Under this program, all tank cars with stub sills must be inspected within 7 years, and the concurrent collection of data will enable the AAR to establish a computerized data base for analysis. The tank cars designated under Priority II of the previous (short-term) inspection program are to be inspected and repaired as necessary within 18 months of the date of the circular. The program requires the inspection and repair of stub sills on all jacketed tank cars and all tank cars with nonjacketed thermal protection within 5 years. The stub sills on all other nonjacketed tank cars are to be inspected and repaired within 7 years. Tank cars with accumulated mileage in excess of 400,000 miles must be inspected on an accelerated schedule.

The inspection program requires inspection of welds attaching (a) the stub sill to attachment pads, (b) the stub sill to the head brace (if used), (c) the head brace to the attachment pad, and (d) the attachment pad to the tank. The prescribed inspection procedures require dye penetrant testing or an equivalent method on accessible welds, and fiber optics or equivalent technology on welds that are not accessible, such as those that are covered by a head shield.

On September 3, 1992, the FRA issued Emergency Order No. 17, Notice No. 1[15] that formally directs tank car owners to comply with the stub sill inspection program as implemented in the AAR's O&M Circular No. 1. The FRA estimated that about 80,000 tank cars must be tested within 5 years, and an additional 40,000 tank cars within 7 years. Under the Emergency Order, each tank car owner is required to inspect an equally proportionate number of tank cars over the 5-year or 7-year inspection periods.

Cause of Structural Problems Noted

The structural problems with the dual diameter tank cars, the tank car that failed in Kettle Falls, and the stub sill assemblies pose a potentially serious threat to the public. Therefore, the Safety Board examined the causes of these failures to determine if a common factor contributed to these failures.

Dual Diameter Tank Cars.—The circumferential separation of CONX 9101 resulted from the propagation of a preexisting 21-inch fatigue crack from the inside of the tank to the outside and along the heat-affected zone adjacent to the circumferential weld between the large diameter and transition sections of the tank. The extensive oxide buildup along the fracture plane indicates that the crack existed within the tank for a long period of time. The presence of chevron markings further indicates that the fracture originated from this preexisting crack. Microscopic examination revealed that the area around the preexisting crack exhibited features indicative of a progressive fracture as would be expected from fatigue. Metallurgical examination of the crack surfaces from the corresponding weld area on the B-end of VICX 9019 also found similar results: heavy

[15] Federal Register, Vol. 57, No. 177, dated September 11, 1992, page 41799.

oxidation of the surfaces of the crack, propagation from the inside surface, and indications of high stress fatigue.

The dual diameter tank cars built by GATC and of the same design as CONX 9101 had an extremely high incidence of circumferential cracks in the area of the A2/B2 weld between the transition plate and the large diameter plate along the bottom center of the tank. Of the 108 tank cars inspected, 40 tank cars were found to have cracks in this area. From the random testing of the nationwide fleet of dual diameter tank cars, which was virtually completed as of November 30, 1992, only dual diameter tank cars of the same design as CONX 9101 have been found to have a confirmed crack, although Conoco is conducting its own tests on a second design built by GATC. These results suggest that the problem with cracking near the circumferential welds in the dual diameter tank cars is limited to the one design type used for CONX 9101 and its sister tank cars. Design differences among dual diameter tank cars may include the configuration of the stub sill and the undercarriage, the type of steel used for the tank, the thickness of the tank shell, and the manner in which the transition section is fitted to other sections of the tank. A major difference in design between the CONX 9101 tank car and most other dual diameter tank cars is that the stub sill attachment and reinforcing pad on the CONX 9101 design do not cross the transition joint between the larger diameter tank and the transition section of the tank.

On CONX 9101 and other tank cars of the same design, the inboard end of the stub sills were within a few inches of the circumferential weld between the transition section and the large diameter section. Impact loads from typical operations, such as coupling and the normal startup and stoppage of trains, produced tensile and compressive loads that were transmitted through the stub sill and its attachment pad into the transition plate for CONX 9101 and similarly designed tank cars. Any abnormally high impact loads that may have occurred from rough handling or other causes would also have been transmitted through the stub sill. Because the transition plate is at an angle to the large diameter plate, these loads produced bending stresses along the lower portion of the tank at the circumferential weld between the transition plate and the large diameter plate. Over the 25 to 27 years these dual diameter tank cars have been in service, these bending stresses likely led to the development and propagation of cracks in the heat-affected zone of the weld. The propagation of the crack in CONX 9101 reached the critical point, and resulted in the circumferential failure that occurred in Dragon, Mississippi

Nonpressure Tank Cars.—The last modifications to UTLX 13835 were to have restored the sump area of the tank car to its original configuration. Although the original design required groove welds between the abutting areas of the sump cover and the reinforcement plate, fillet welds were used in this area, which resulted in a stress concentration in the tank shell between the sump cover and the reinforcing plate. Cyclic stresses in these members, together with the stress concentration at the base of the notch, led to the initiation of the large fatigue crack between the sump cover and the reinforcing plate.

The cracking of the tank that produced leakage of the product resulted from overstress fracturing that originated from two regions slightly removed from and on either side of the large preexisting fatigue crack. Longitudinal tensile loading of the tank during train startup with the downward bending load on the bottom of the tank from the product and the reduction in the cross-section due to the fatigue crack most likely caused the stress to intensify at the two locations on either side of the fatigue crack, resulting in the initiation of the fracture.

Stub Sill Failures.—Because the stub sill provides a physical link between the tank and the coupler for the tank car, any impact loading from the movement of the tank car and train operations will be transmitted to and through the stub sill. Load bearing surfaces of the stub sill and welds between the sill, the attachment plates, and the tank are likely to be areas of high stress and subject to cyclic loading that can lead to fatigue and overstress failures as previously described in this report. In its report on the 1985 accident at Elkhart, Indiana, the Safety Board specifically noted that the head-to-stub sill weld attachment is a critical stress area that is subject to severe mechanical stress. The failure of the head-to-stub sill weld on the tank involved in the Elkhart accident demonstrates the potential risk of cracks propagating into the tank shell from welds of the stub sill assembly. Complete fracture and separation of the stub sill also increase the possibility of derailment and of damage to the tank car that results in release of its product. Further, the failure of these stub sill assemblies in transportation indicates that propagating cracks are not being detected during any of the periodic tests and inspections that may have been performed on the tank cars.

Detection of Structural Defects

The structural failures of the dual diameter tank cars, the nonpressure tank car involved in the Kettle Falls incident, and the stub sills on various types of tank cars all occurred in areas that were subject to high stress and/or cyclical loading. Also, the failures of the CONX 9101 in Dragon, Mississippi, and UTLX 13835 in Kettle Falls, Washington, resulted from preexisting cracks that had gone undetected until the tank failed in transportation. Many of the documented failures of the stub sills also occurred because cracks in various welds between the attachment pads and the stub sill assembly had gone undetected and propagated into the stub sill, resulting in the separation of the stub sill from the tank car.

All of these incidents prompted the FRA and the AAR to initiate specific testing and inspection programs to determine the extent of the safety problems in tank cars of similar design and construction. Specifically, an extensive stub sill inspection program is underway. Also, the testing and inspection of a representative sample of the fleet of dual diameter tank cars under the FRA's Emergency Order 16 was prompt and responsive to Safety Recommendation R-92-7. The virtual completion of the random testing of the fleet of dual diameter tank cars and the implementation of an on-going inspection program for dual diameter tank cars found to be susceptible to cracking meet the intent of the recommendation. Therefore, the Safety Board has classified Safety Recommendation R-92-7 "Closed—Acceptable Action."

However, the stub sill and dual diameter inspection programs implemented by the FRA and the AAR were initiated in response to structural failures that occurred while the tank cars were in transportation, and not as the result of any periodic testing and inspection program.

The Safety Board had previously recognized limitations of in-service testing and inspections during its investigation of the Elkhart, Indiana, accident. In its report, the Safety Board concluded that in-service testing and inspection procedures do not provide assurance that head deficiencies will be identified routinely and monitored properly. Therefore, on January 15, 1986, the Safety Board issued a safety recommendation to the FRA to:

> *R-85-124*
>
> Develop a recertification program for tank cars in hazardous materials service fabricated prior to 1967, which will provide assurance that undercut welds in tank car heads are identified and corrected.

In response to this recommendation, the FRA initiated three research projects in 1987 to address (1) cracking in the stub sill area; (2) stress relief and postweld heat treatment of welds in stub sill tank cars; and (3) stress relief of tank cars. The first two research studies have been completed, but the third study is still underway. Also, in a separate response to this recommendation, the FRA issued an Advanced Notice of Proposed Rulemaking (ANPRM) under Docket HM-201, which is discussed later in this report. (The ANPRM requested, in part, information about the types of repairs that could lead to cracks and techniques to detect such cracks.) Safety Recommendation R-85-124 is classified "Open—Acceptable Response."

Despite actions taken by the FRA in response to Safety Recommendation R-85-124, the Safety Board remains concerned about structural defects that may go undetected and lead to a sudden failure of a tank car during transportation. The Safety Board believes that defects found in the dual diameter tank cars, the nonpressure tank car involved in the Kettle Falls accident, and stub sills on various types of tank cars must be detected and corrected before they reach a critical size and destroy the structural integrity of the tank car. Consequently, the Safety Board examined the effectiveness of Federal regulations and industry standards pertaining to the periodic testing and inspection of tank cars to detect structural defects.

Inspection and Testing of Tank Cars

Background

Standards for testing tank cars were first developed and implemented by industrial associations. For example, the predecessor to the AAR, the Master Car Builder's Association, published requirements for a hydrostatic test in the 1918 issue of its *Specifications for Tank Cars*. A representative from the AAR believes the hydrostatic test served as a leak-test to prove the integrity of joints in riveted tank cars. The FRA also indicated that hydrostatic pressure tests were intended to locate leaks associated with tank shell plates and loose rivets and to detect metal deformations in areas of reduced wall thickness. The early tank cars were of riveted construction, and, according to the FRA, the hydrostatic test was effective in locating imperfections associated with riveted tank cars such as riveted joints, nozzles, tank anchors, and reinforcements. When welded tank cars were introduced into service in the 1930s, they also were subjected to hydrostatic tests. (Today, all newly constructed tank cars used for the transportation of hazardous materials are of welded construction. According to the AAR, about 136 riveted DOT specification tank cars are still in service.)

From the early 1900s to the establishment of the DOT in 1966, the Interstate Commerce Commission (ICC) had the statutory authority and responsibility at the Federal level to regulate the transportation of hazardous materials by surface.[16] The ICC looked to industry-developed standards for surface transportation of hazardous materials, and was authorized in 1921 by law (41 Stat. 144) to use the services of the AAR's Bureau for the Safe Transportation of Explosives and Other Dangerous Articles (now the Bureau of Explosives).

With the establishment of the DOT in 1966, regulatory authority over the transportation of hazardous materials in all modes was transferred to the DOT. The existing ICC regulations for the surface transportation of hazardous materials were carried over and redesignated under Title 49 Code of Federal Regulations (49 CFR) that were to be administered and enforced by the new DOT. Specific regulations for the periodic inspection and testing of DOT class tank cars are covered under the provisions of 49 CFR 173.31(c) and apply to DOT class 103, 104, 105, 106, 107, 109, 110, 111A, 112, 113, 114, and 115 tank cars.[17] Since the transfer of responsibility to the DOT, there have not been any major changes to the inspection and testing requirements.

Organizations such as the AAR and the Chlorine Institute—whose members include railroads, tank car owners and manufacturers, and certain chemical manufacturers and shippers—have also published testing and inspection standards and recommendations for tank cars that supplement Federal regulations.

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[16] The evolution of Federal regulatory programs concerning the transportation of hazardous materials was addressed in a 1981 National Transportation Safety Board Safety Report ("Status of Department of Transportation's Hazardous Materials Regulatory Program," NTSB-SR-81-2).

[17] DOT class 103 and 104 tank cars are older types of tank cars, and are not common in rail transportation. The tank cars most commonly used today for the transportation of hazardous materials are the DOT class 105, 106, 110, 111A, 112, and 114 tank cars.

Inspection and Testing Requirements

Current DOT Requirements.—Under 49 CFR 173.31(c)(2), each single-unit[18] tank car tank must be hydrostatically tested by completely filling the tank and manway nozzle or expansion dome with water or a comparable liquid and applying the specified pressure for 10 minutes if the tank is not insulated, or 20 minutes if the tank is insulated. The hydrostatic test pressure will vary depending on the design pressure of the tank car. For example, general service tank cars (DOT class 111A) typically have design pressures of either 60 or 100 psig. Pressure tank cars (DOT classes 105, 109, 112, and 114) have design pressures ranging from 100 to 600 psig. The regulations require that a tank exhibit no leakage or "evidence of distress" to pass a hydrostatic test. The tank insulation and jacket do not have to be removed unless there is a drop in pressure, which would indicate a leak. Tanks in service 10 years or longer must also have an internal visual inspection.

Periodic testing intervals vary with the type of tank car and the commodity carried. For example, nonpressure tank cars that are typically used to transport corrosive materials (DOT specifications 111A60W2, 111A60W5, or 111A100W5) must be tested every 5 years up to the first 10 years the tank car is in service, 3 years between 10 and 22 years of age, and then every year thereafter. Tank car UTLX 13835 (involved in the Kettle Falls, Washington, accident) was constructed in 1981 and was subject to these inspection intervals. Because UTLX 13835 was built in 1981 and had just passed the 10-year threshold, the periodic test interval changed from every 5 years to every 3 years. Most pressure tank cars (DOT classes 105, 112, and 114) must be retested every 10 years after the tank car enters service. Some dual diameter tank cars, such as CONX 9101 that was involved in the accident at Dragon, Mississippi, are in this category. General service tank cars (DOT specification 111A60W1, 111A100W1, and 111A100W3) that are most often used for the transportation of flammable liquids are not required to have periodic hydrostatic tests until the tank car has been in service for 20 years, and thereafter every 10 years.

Under the provisions of 49 CFR 215.203(b), any type of railroad freight car, including a stub sill tank car, may remain in service until the freight car is 50 years old based on the original construction date of the underframe. A full (continuous) sill tank car may remain in service indefinitely if the underframe is rebuilt and the tank otherwise meets all Federal requirements. Under AAR standards,[19] a stub sill tank car must be retired from service at or before the underframe reaches 40 years. If the underframe and draft systems on the car are rebuilt, the stub sill tank car may remain in service for 50 years. Tanks on full sills have no age limit, and may be mounted on new frames. According to an AAR representative, most freight cars are typically retired at 40 years.

Single-unit tank car tanks that are lined with glass, rubber, lead, or a 1/16-inch thickness of elastomeric polyvinyl chloride or polyurethane are not required to be periodically tested. Interior heater coils must also be hydrostatically tested when the tanks are tested; exterior coils do not require a hydrostatic test. Heater coils on lined tanks must be hydrostati-

[18] Single-unit tank cars are single tanks or multi-compartment tanks that are mounted on or form part of the car structure. Newly constructed single-unit tank cars must not have a water capacity exceeding 34,500 gallons.

[19] The Association of American Railroads. 1990. Manual of standards and practices, Section C, Part III –Specifications for tank cars; Section 1.3.10—Age limits. Washington, DC.

cally tested at the prescribed intervals even though the tank is not hydrostatically tested. Safety relief valves must also be tested, typically at one half of the interval for the tank test. The intervals for testing safety relief valves range between 1 and 10 years.

The RPI estimated that of the 121,000 tank cars owned or operated by RPI members, about 14,400 are hydrostatically tested each year. The RPI indicated there are a "small number" that fail because of leaking seals and other components, but the RPI is not aware of any tank cars that failed a hydrostatic test because of structural defects.

Under the regulations contained in 49 CFR Part 215, the FRA requires predeparture inspections for all types of rail freight cars, including tank cars. The regulations specifically require inspection of the car structure, suspension system, and the draft system. The regulations also identify the types of defects in the car structure and the suspension and draft systems that would prohibit the freight car from entering or continuing in service. Predeparture inspections that must also be performed at each location where a freight car is placed in a train are visual examinations performed by qualified railroad freight car inspectors. Appendix D to 49 CFR Part 215 describes inspections that are performed at locations where qualified inspectors are not on duty. Under these circumstances, the freight cars must be inspected for "imminently hazardous conditions...that are likely to cause an accident or casualty before the train arrives at its destination." Appendix D further describes these conditions as "readily discoverable" by the train crewmember.

Regulatory Initiatives.—The FRA and the RSPA published an ANPRM on December 8, 1987,[20] under Docket HM-201. According to the ANPRM, the FRA and the RSPA were considering new safety standards that would require railroad tank car owners and repair facilities to inspect for cracks after certain tank repairs to assure that no cracks exist. The RSPA and FRA also indicated in the ANPRM that revision of existing periodic reinspection requirements was also being considered to more adequately detect cracks, pits, corrosion, lining flaws, thermal protection flaws, and other defects. The ANPRM stated that any new safety standards or revised requirements for periodic inspections could include specific inspection techniques to assure that small defects, which may grow in size, are properly identified and repaired or monitored.

The FRA and the RSPA noted their concern about the detection and repair of cracks and other defects arising from tank repairs and from causes other than tank repairs. The FRA and the RSPA indicated that the lack of specificity in the internal inspection requirements of 49 CFR 173.31(c) and the absence of any internal inspection requirements for multi-unit tank car tanks may result in the nondetection of small defects that may grow in size and lead to tank failure. Both agencies also expressed concern about the detection and repair of defects that are present on the external surface of tank car tanks but that are obscured by insulation.

Through the ANPRM, the FRA and the RSPA requested comments and information about (1) the types of repairs that are likely to lead to undetected cracking, (2) nondestructive testing techniques such as acoustic emission, ultrasonic, magnetic particle, and radiography to detect cracks and other defects; (3) appropriate repair procedures; and (4) alternatives to the repair of defects such as special handling, special train placement, and more frequent inspections. Because the rulemaking is still under

[20] Federal Register, Vol. 52, No. 235, dated December 8, 1987, page 46510.

development by the FRA and the RSPA, the FRA would not comment on the scope of a Notice of Proposed Rulemaking (NPRM) or project a publication date for the NPRM.

The Safety Board asked the FRA whether it was considering testing and inspection standards based on a damage-tolerance philosophy, which is widely used in the aviation industry. Under this philosophy, defects in structural components are presumed to exist, and the growth rate and the critical point at which sudden failure can occur are determined. The propagation characteristics of the defect and the sensitivity of the testing method employed determine the testing interval of the component. In response to the Safety Board's inquiry, the FRA did not indicate that HM-201 or any other regulatory project incorporated this approach for the testing and inspection of tank cars. However, the FRA indicated that Emergency Order 16 (the program implementing random testing of all designs of dual diameter tank cars) and two recent FRA task force reports on the detection of defects in the welds for body stiffeners and anti-shift brackets on tank cars incorporated a damage-tolerance philosophy.

Industry Standards and Practices.—The AAR has published procedures that supplement the DOT regulations for the periodic testing and inspection of tank cars. The DOT requirements are reprinted in Appendix D to the AAR's *Manual of Standards and Practices, Section C, Part III-Specifications for Tank Cars*. The AAR also published a circular letter in July 1991 that contains specific standardized procedures for the retest of tank car tanks, safety valves, and interior heating systems in accordance with DOT requirements.

The AAR's Interchange Rule 88B.1 requires "a thorough inspection" and repair of the tank car underframe and the truck components[21] following major repairs, at the time of the tank retest, and for all tank cars that are recalled through early warning letters or maintenance advisories. Rule 88B.1 does not address the use of nondestructive testing (NDT) as part of the inspection. In January 1992, the AAR's Tank Car Committee also adopted new requirements for testing the integrity of rubber linings in tank cars used for the transportation of certain high-strength acids. Under these requirements, the linings must be tested every 5 years for the first 10 years of service, and every 2 years thereafter from the date of the lining. (FRA requirements in 49 CFR 173.31(c) are for a visual inspection of the lining every 10 years.)

The AAR has also adopted specifications in its *Specifications for Design, Fabrication, and Construction of Freight Cars* for the fatigue analysis on new designs of rail freight cars, including tank cars. The purpose of the fatigue analysis is to determine the stress levels below which cracks should not initiate over the expected life of a freight car. The components that require the fatigue analysis include the bolsters, center and stub sills, and the buff and draft attachments and supports. The AAR stated that it has not previously adopted a damage-tolerance philosophy regarding the design of tank cars. The AAR has indicated, however, that this approach may have merit for specific applications, such as cracking in stub sill attachment welds.

The Chlorine Institute, an association of companies involved in the manufacture, transportation, and use of chlorine, also has its own inspection and testing recommendations for tank cars in chlorine

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[21] The underframe and truck components are those structures other than the rail tank itself. The underframe and truck components support the tank and include the trucks, body bolsters, the stub sill and other draft components of the tank car.

service. The Chlorine Institute relies on thorough visual examinations of the interior and exterior of the tank rather than other NDT methods for the detection of defects in the tank.

Effectiveness of Available Testing Methods

The Safety Board asked the FRA, the AAR, the RPI, Conoco, and Vista to comment about the effectiveness of hydrostatic tests and other methods of NDT.

The FRA acknowledged that hydrostatic tests and visual inspections have limitations, most notably the detection of fatigue cracks or other defects that have a point of criticality above the hydrostatic test pressure. In such cases, the crack or defect will not fail. The FRA stated that the effectiveness of any visual inspection depends on the ability of the inspector to consistently and repetitively detect imperfections and then determine which imperfections are defects requiring repair.

The AAR stated that because of the accidents at Dragon and Kettle Falls, the AAR has serious questions about current DOT requirements and AAR standards for the periodic testing and inspection of tank cars. The AAR stated that these accidents indicate that tank car tanks appear to be passing the required hydrostatic tests despite the presence of major flaws in the tanks. Conoco and Vista expressed similar views.

The RPI stated that the current DOT requirements are sufficient for the purpose intended, which is to detect leaking seals and "other components," and not to detect cracks or other structural defects. The RPI believes that the structural integrity of the tank is ascertained by the visual examination that is performed in conjunction with the hydrostatic test. The RPI also indicated that the inspection intervals are sufficient based on the overall safety record of the tank cars.

The FRA is evaluating and reviewing NDT methods (such as acoustic emissions, ultrasound, magnetic particle testing, dye penetrant, and radiography as used on the dual diameter tank cars) as part of the HM-201 rulemaking and for the qualification of their continued use for the inspection of tank cars. The AAR's Tank Car Committee has been evaluating the use of acoustic emissions for the inspection of tank cars, and concluded that acoustic emissions "may be utilized to evaluate all tank car tanks and all tank car structures." The RPI indicated that acoustic emission is still under development for use in the tank car industry. Acoustic emission testing can be used on tank cars without substantial dismantling of the tank car, such as the removal of insulation, a jacket over the tank shell, or interior lining. According to the RPI, acoustic emissions testing can only indicate the approximate location of a defect, and its accuracy is highly dependent on the skill of the technician who conducts the test and interprets the results.

According to the RPI, ultrasound can detect nonsurface defects. Because this method requires access to only one surface and utilizes a small sensor, it can be used without major dismantling of a tank car. The RPI stated that this method is effective for inspecting a small area for a specific type of defect, but the method is too slow for conducting general inspections. Ultrasound also requires a high level of skill to interpret the results.

The RPI indicated that radiography is the established method to detect subsurface defects and is often used during construction of tank cars. The RPI further indicated that substantial dismantling of a tank car may be required because both opposing surfaces of the area to be radiographed must be accessible. Consequently, radiography can often be very slow and expensive.

Dye penetrant and magnetic particle testing are used to detect surface defects. The RPI stated that the surface must be accessible and in reasonably smooth condition, and that the two methods require moderate skill levels.

Testing of Dual Diameter Tank Cars With Known Structural Defects

Hydrostatic Test Results.—To test the effectiveness of the DOT-mandated hydrostatic test, the Safety Board requested in April 1992 that Conoco and Vista each conduct hydrostatic tests on two of their dual diameter tank cars in which cracks in the circumferential weld area between the transition plate and large diameter plate had been previously detected by radiography. The hydrostatic tests were conducted in accordance with the requirements of 49 CFR 173.31(c).

According to a Vista representative, x-ray and ultrasonic testing indicated that the first Vista tank car, VICX 9006, had a crack at the weld joint of the transition and large diameter sections on both the A- and B-ends of the tank car. Through testing, the crack at the A-end was reported to be 42 inches long and 0.5 inch deep, and the crack at the B-end was reported to be 39 inches long and 0.1 inch deep. The test results for the second Vista tank car, VICX 9013, indicated that it had a 13-inch crack at the same weld at the B-end, and a 0.5-inch transverse crack (perpendicular to the circumferential weld) at the A-end. Both tank cars were hydrostatically tested on May 7, 1992, at a pressure of 365 psig, 25 psig above the required test pressure. Both tank cars held the test pressure for 20 minutes without leakage. Both tank cars had been previously tested in 1989 and were not due for another hydrostatic test until 1999.

X-ray and ultrasonic testing of the two Conoco tank cars, CONX 9121 and CONX 9127, indicated that each had an 18-inch crack at the circumferential weld area between the transition plate and the large diameter plate at the B-end. The depth of the cracks on CONX 9121 and CONX 9127 were estimated as 0.31 (5/16) inch and 0.41 (13/32) inch, respectively. Under the hydrostatic tests conducted by Conoco on May 11 and 12, 1992, each tank car was pressurized to 150 psig for 10 minutes. The pressure was increased to 200 psig for 30 minutes, and then to 340 psig for 10 minutes. Acoustic emission testing was done simultaneously with the hydrostatic test. Both tank cars held each level of pressure for the indicated times without leakage. Acoustic emission testing detected the crack on CONX 9127, but did not detect the crack on CONX 9121. A representative from the company performing the acoustic emission tests indicated that because the tests on CONX 9121 and 9127 did not use the prescribed number of sensors and were not conducted in accordance with the procedures accepted by the AAR, the test results should not be used to evaluate acoustic emission testing against hydrostatic testing. CONX 9121 had been previously hydrostatically tested in 1991 and was not due for a retest until 2001. CONX 9127 had been previously hydrostatically tested in 1986 and was not due for another test until 1996.

Acoustic Emissions Tests.—To determine the effectiveness of acoustic emissions testing for the detection of structural defects in the tank car shell, the AAR's task group on acoustic emissions, at the request of the FRA, performed tests on September 1-4, 1992, on tank cars CONX 9115, 9117 and 9123. The three tank cars were sister cars to CONX 9101, the tank car involved in the Dragon accident, and all had been previously radiographed at the direction of the FRA following the Dragon accident. As a result of the radiographic inspections, CONX 9115, 9117, and 9123 were found to have cracks and other defects in the circumferential welds ranging from 1 inch to 32 inches in length. In addition to the acoustic emissions testing, each tank car was also hydrostatically tested in accordance with DOT regulations at a test pressure of 340 psig.

The acoustic emissions tests proceeded slowly because of difficulties in calibrating the test equipment. The tests were performed in an open area of the welding shop that was exposed to wind, dust, and electrical interference from the welding equipment. The technicians performing the calibration tests attributed the difficulty in calibrating the test equipment to the cumulative effect of these environmental factors.

The task group reported that the acoustic emissions tests indicated weld defects in each of the three tank cars and that the results of the acoustic emissions tests correlated well with the results of the radiographic testing. All tank cars also passed the hydrostatic test.

Evaluation of Current Testing Requirements

Existing DOT requirements for periodic testing and inspection of tank cars depend on hydrostatic tests performed in conjunction with visual inspections to detect structural defects in single-unit tank car tanks. Hydrostatic testing that was initially required as a means of leak-testing the seams of riveted tank cars appears to be an appropriate method to test the integrity of gaskets, seals, and other fittings on welded tank cars. However, the hydrostatic tests conducted by Vista and Conoco on four dual diameter tank cars with known structural defects demonstrates the ineffectiveness of hydrostatic testing as means of assessing the structural integrity of a welded tank. All four dual diameter tank cars successfully passed hydrostatic tests even though they had major cracks in the circumferential weld area between the transition and large diameter sections. Three other dual diameter cars with known cracks, owned by Conoco, passed hydrostatic tests that were conducted in conjunction with acoustic emissions testing. Also, 40 of 108 dual diameter tank cars of the same design as CONX 9101 were found to have cracks even though 25 of these tank cars had been tested and inspected during or after 1988; 13 of these tank cars were tested and inspected during 1991 and 1992. Although the rate of crack propagation in these tanks was not determined, it is unlikely that cracks in all of these tank cars would have first developed during the relatively recent time period since the last hydrostatic tests were performed. Further, UTLX 18385, which failed because of a preexisting crack in the sump area, was hydrostatically tested only about 1 month before it failed on the first trip following the hydrostatic test. Because hydrostatic pressure tests were successfully performed at higher pressures (300-400 psig) on the dual diameter tank cars with known cracks, the Safety Board does not believe that the hydrostatic test (at a pressure of 100 psig) conducted in February 1992 contributed to the failure of the nonpressure tank, UTLX 18385. Further, the Safety Board believes that hydrostatic tests are not effective for the detection of structural defects in welded tank cars.

Current DOT regulations also require that a visual inspection of the interior and exterior of the tank car be conducted in conjunction with the hydrostatic test. Visual inspections are useful for the detection of large surface defects that are located on exposed surfaces. Defects on surfaces that are obscured or hidden by corrosion, insulation, an interior tank lining, or a tank jacket will not be detected during a visual inspection. Further, subsurface cracks and defects will not be detected by a visual inspection. CONX 9101, which failed at Dragon, had corrosion on the interior surface of the tank plate, and a jacket over the exterior surface of the tank plate. The Safety Board doubts that a visual inspection would have been sufficient to detect the preexisting cracks in CONX 9101 that resulted in its structural failure. UTLX 13835, which failed at Kettle Falls, had a preexisting crack that initiated at the outside diameter and was not detected by the visual inspection performed the month prior to the incident.

Currently, the intervals for periodic testing and inspection of tank cars are based on the type of commodities transported. Tank cars that transport corrosive materials must typically be tested and inspected more frequently than pressure tank cars that transport flammable and compressed gases. General service tank cars that are most commonly used for the transportation of flammable liquids are not required to be periodically tested and inspected until the tank car is 20 years old, and then every 10 years thereafter. Although the type of commodity transported should be a consideration, other factors—such as the likelihood of initiation and the rate of propagation of cracks and other defects in the operating environment—should also be considered.

The DOT regulations also fail to require an effective inspection of the stub sills and other structural members apart from the actual tank. The predeparture inspections that must be performed by traincrews are intended to detect obvious conditions that will prevent a train from arriving safely at its destination. The practices of organizations such as the AAR, the RPI, and the Chlorine Institute generally supplement the DOT regulations by providing specific procedures for conducting DOT-required tests and inspections, and in certain applications exceed DOT requirements. Although these industry-developed practices provide a definite benefit, the Safety Board does not believe these practices resolve the problems with the detection of structural defects in tank cars transporting hazardous materials.

Consequently, with current DOT regulations and industry-developed standards, major structural defects on a tank car can go undetected until a catastrophic failure occurs. As a result, the FRA, the AAR, and tank car owners and manufacturers are reacting to structural problems after an accident or series of accidents, rather than detecting structural problems through an effective periodic testing and inspection program.

The Safety Board recognizes and commends the prompt actions of the FRA, the AAR, and the tank car owners and manufacturers in responding to the problems with the dual diameter tank cars and to the failure of UTLX 13835. The Safety Board is also aware of the continuing efforts of the FRA and the AAR to resolve the problems with stub sill separations.

However, the Safety Board believes that an effective program of periodic testing and inspection must be implemented to detect major structural defects before they have the potential of causing catastrophic failures. The structural failures described in this report all occurred in areas subject to high stress or cyclic loading, which resulted in the development of fatigue cracks that propagated, undetected, to critical length.

The Safety Board believes that a damage-tolerance approach to periodic testing and inspection of railroad tank cars would substantially increase the likelihood of detection of cracks and other defects before they result in catastrophic failure. The elements of a damage-tolerance approach should (1) identify areas and components on tank cars that are prone to failure from high stress and fatigue, and (2) determine inspection intervals that are based on the defect size detectable by the inspection method used, the stress level, and the crack propagation characteristics of the structural component.

The Safety Board recognizes that the current NDT techniques such as acoustic emissions, ultrasound, radiography, dye penetrants, and magnetic particle testing have differing capabilities and limitations. Although the AAR's Tank Car Committee is investigating the use of acoustic emissions testing on tank cars, difficulties encountered with the acoustic emissions testing of three dual diameter tank cars owned by Conoco demonstrate that acoustic emissions testing of rail tank cars needs further refinement to be a viable inspection method in this application. The Safety Board also believes that certain NDT techniques may be more appropriate than others for different structures on the tank car. Also, it may be necessary to utilize two or more inspection techniques to properly inspect certain configurations of tank cars, such as those with jackets or thermal insulation. The capabilities of the inspection methods used are the major determinant of the inspection intervals in the damage-tolerance approach to continued safe operation of the tank cars. The Safety Board, therefore, urges the FRA, the AAR, the RPI, and the Chlorine Institute to evaluate NDT techniques and to determine how such techniques can best be applied for periodic testing and inspection of all tank cars that transport hazardous materials.

The Safety Board believes that standards for periodic testing and inspection, based on a damage-tolerance methodology, should be implemented under Docket HM-201 for rail tank cars. Further, the Safety Board believes that every effort should be made to expedite the rulemaking under Docket HM-201. Consequently, the Safety Board urges the FRA and the RSPA to develop and promulgate requirements for the periodic testing and inspection of rail tank cars that help to ensure the detection of cracks and other defects before they can grow to critical length and cause catastrophic failure of the tank car.

Conclusions

1. The circumferential separation of tank car CONX 9101 resulted from the propagation of a preexisting 21-inch fatigue crack from the inside of the tank to the outside and along the heat-affected zone adjacent to the circumferential weld between the large diameter and the transition sections of the tank.

2. The failure of tank car UTLX 13835 occurred because of the presence of a preexisting and undetected fatigue crack in the area of the sump cover and the reinforcement plate that were located at the bottom center of the tank car.

3. The preexisting fatigue crack that was located between the overstress origins on UTLX 13835 most likely existed when the tank passed the DOT-required hydrostatic test and visual inspection in February 1992.

4. Hydrostatic tests and visual inspections at arbitrary intervals are not effective to detect structural defects in welded tank car tanks or to detect defects at high stress areas where stub sills or other components are attached to tanks before sudden and complete failure.

5. The use of acoustic emission, ultrasonic, and other nondestructive testing methods, if applied at appropriate intervals based on damage-tolerance concepts, could detect existing cracks prior to catastrophic failure of rail tank cars; however, more research is needed to determine the best methods to be used under given conditions and the appropriate inspection intervals.

Recommendations

As a result of this special investigation, the National Transportation Safety Board made the following recommendations:

— *to the Federal Railroad Administration, U.S. Department of Transportation:*

Evaluate, with the cooperation and assistance of the Association of American Railroads, the Railway Progress Institute, and the Chlorine Institute, nondestructive testing techniques and determine how such techniques can best be applied for periodic testing and inspection of all tank cars that transport hazardous materials. (Class II, Priority Action) (R-92-21)

Develop and promulgate, with the Research and Special Programs Administration, requirements for the periodic testing and inspection of rail tank cars that help to ensure the detection of cracks before they propagate to critical length by establishing inspection intervals that are based on the defect size detectable by the inspection method used, the stress level, and the crack propagation characteristics of the structural component (requirements based on a damage-tolerance approach). (Class II, Priority Action) (R-92-22)

— *to the Research and Special Programs Administration, U.S. Department of Transportation:*

Develop and promulgate, with the Federal Railroad Administration, requirements for the periodic testing and inspection of rail tank cars that help to ensure the detection of cracks before they propagate to critical length by establishing inspection intervals that are based on the defect size detectable by the inspection method used, the stress level, and the crack propagation characteristics of the structural component (requirements based on a damage-tolerance approach). (Class II, Priority Action) (R-92-23)

— *to the Association of American Railroads, the Railway Progress Institute, and the Chlorine Institute:*

Evaluate, under the guidance of the Federal Railroad Administration, nondestructive testing techniques and determine how such techniques can best be applied for periodic testing and inspection of all tank cars that transport hazardous materials. (Class II, Priority Action) (R-92-24)

As a result of this special investigation, the National Transportation Safety Board classified the following recommendation to the Federal Railroad Administration "Closed."

R-92-7

Require owners and operators of dual diameter pressure tank cars to inspect by x-ray radiography and/or other appropriate means a representative sampling of their dual diameter tank cars for evidence of cracks and other serious defects in the circumferential welds between the transition and larger diameter tank shell plates. Based on these inspections, assess whether the total fleet of dual diameter pressure tank cars should be inspected immediately for evidence of cracking, and if periodic inspections should be required.

Status: "Closed—Acceptable Action."

By the National Transportation Safety Board

Carl W. Vogt
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Susan M. Coughlin
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John K. Lauber
Member

Christopher A. Hart
Member

John A. Hammerschmidt
Member

Adopted: December 22, 1992

END
FILMED

DATE:
3-22-93

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